A RECONSTRUCTION

OF THE

NUCLEAR MASSES IN THE LOWER PORTION OF THE HUMAN BRAIN-STEM

BY

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INTRODUCTORY.

CHARACTER OF WORK UNDERTAKEN.

For the purpose of securing more accurate knowledge of the masses of gray matter in the rhombencephalon, this work was undertaken, with the idea that by a careful wax-plate reconstruction of the nuclear material in one brain-stem the present conception of their morphology might be advanced. The study has been purely morphological, with no attempt to introduce other elements. With the realization that considerable individual variation exists, even on macroscopic examination in the surface anatomy of the medulla and pons, the conclusion becomes obvious that the morphological studies here presented deal with only one brain-stem and in the finer details the findings will not endure for all types. However, it is believed that such a study of the form of the different gray masses in the caudal portion of the brain-stem may prove advantageous in the ultimate establishment of the finer anatomy and may perhaps serve as a basis for somewhat more extensive studies.

In order that the model might exhibit as many of the characteristics of the morphology of the medulla and pons as possible, different masses were retained in part on the two sides of the median raphe. In the most caudal portions, the masses modeled are identical, but at the decussatio pyramidum the outer limits of the formatio reticularis are modeled on the one side, while on the other the anterior column is sharply cut off from the central gray matter. In this way the scattered masses of the formatio are brought out, as well as the corresponding separation of the anterior column from the nuclear material about the central canal. This modeling of the formatio reticularis is continued cephalad, so that the one side of the reconstruction exhibits the morphology of the formatio reticularis and the markings of the floor of the fourth ventricle, while the opposite half shows the isolated nuclear masses segregated from each other. These differences in the two halves of the reconstruction are explained in more detail in the various descriptions comprising this paper.

The literature on the morphology of these nuclear structures in the human brain-stem is wofully scant. The most important studies are those made by Dr. Florence Sabin, of the reconstruction of the nuclear masses and fiber paths of the brain-stem of a new-born babe. Most of the other references to the literature deal not with actual morphology, but with plotted limits, and it is to avoid such diagrammatic representations that this study is presented.

Throughout this paper, the terms "nuclear material" and "gray matter" have been used almost synonymously. Neither of the terms is satisfactorily descriptive, but by them are meant the collections of nerve-cells with attending neuroglia-elements, which go to make up the easily recognizable nuclei, the various substantiæ, and the formatio reticularis. Considered narrowly, these masses are merely those in which the cellular elements predominate in amount over the fiber strands. Of the other terms used in this paper, little need be said. "Cephalic," "superior," and less frequently "upper" are the adjectives applied in the sense of "toward the cerebrum," while "caudal," "inferior," and "lower" are used to designate the direction of "away from the cerebrum" or "toward the tail."

METHOD OF RECONSTRUCTION.

To secure the third dimension in this morphological study, the method of Born was adopted—reconstruction by means of wax plates of uniform thickness. By a projection apparatus, drawings of uniform enlargement were made from a series of sections of the human adult brain-stem. This series of over two thousand serial sections comprises one of the "loan collections" in the neurological series of the Anatomical Department of the Johns Hopkins Medical School. (Brain-Stem No. 2627). The brain-stem was fixed in formalin, embedded in celloidin, and cut transversely, the sections being 40 microns in thickness. The staining was done by the Weigert-Pal method, with counterstaining by carmine. In this present work every fifth section was projected with a constant magnification of 15 diameters; the drawings were made and then corrected by examination of the slide under low magnification; the corrected drawings were transferred to wax plates and the plates were cut by means of a knife. The magnification of 15 diameters was selected because it secured a plate of convenient thickness (3 millimeters) and also because it practically coincided with the enlargement used by Miss Sabin in her reconstruction of the brain-stem in the new-born babe (14.5 diameters).

The sections in this series are well stained and no difficulty was experienced in differentiating between nuclear material and the fiber bundles. The masses of gray matter were outlined with consideration chiefly for the general appearance of the nuclear mass and with much less regard for the individual cells comprising the mass. This differentiation on this grosser outline leads, it is believed, to a better and truer conception of the morphology of the masses. In cases where doubt existed, and in the determination of the final limits of the gray matter under consideration, the identification and location of the characteristic cells of the nucleus were regarded as necessary for the correct establishment of the limits of the nuclear material. Comparison of the results given by both of these methods—the first with moderate magnification, and the second with magnification high enough to permit identification of characteristic cells—showed that in no case would the limits, as

obtained by consideration of the general appearance of the nuclear masses, be changed by more than the thickness of one plate. In practically all cases the limits determined by the two methods coincided. However, in order to be certain of the limits in all cases, the drawings were carefully corrected under magnification high enough to show both the individual cells and the fine structure of the gray material.

One of the most important factors in securing a model which shall present true relations and correct morphology is that of accurate piling of the individual plates. The controls used for the piling of the plates in this work were (1) the external form of the adult brain-stem; (2) the form of the floor of the fourth ventricle; (3) sections of the brain-stem cut in the sagittal plane. As, unfortunately, no drawing of the brain-stem from which these sections were obtained had been made before cutting, the use of another brain-stem, as a guide for piling, was rendered necessary. It was found that the external form best served as the pattern for the correct piling of the plates in the caudal part of the medulla, while cephalad to this the floor of the fourth ventricle, together with the external form, proved most reliable. Sagittal sections of the brain-stem from the neurological loan collections of the Anatomical Laboratory were used as further controls, but were not considered to be wholly reliable, because of the chance of error in the exact plane of cutting; for it was realized that variations in two planes might occur in these sections, the correction of which could only be worked out after considerable study and with reference to certain points assumed to be constant; and these so-called constant points are really constant only in the transverse diameters and can control only the plane transverse to the long axis of the brain-stem. Such points, *e. g.*, are the inferior and superior ends of the hypoglossal nuclei, which in this series occurred in the same sections in both instances—good evidence apparently that the general planes of the model were correct.

The lateral deviations of the model were corrected on the assumption that the anterior fissure of the cervical spinal cord and of the medulla, the posterior fissure of the cervical cord, and the median sulcus of the floor of the fourth ventricle, all formed straight lines. Inspection of a number of brain-stems led to this conclusion and it was decided that if these were considered as constant fixed lines, less error could occur in the planes of the model than if other guides were adopted. The other planes were controlled, as far as possible, by the sagittal sections, but chiefly by the external form and by the morphology of the floor of the fourth ventricle. One of these transverse planes was considered established by the occurrence (as mentioned above) of the caudal end of both hypoglossal nuclei in one section, and of the posterior poles of the inferior olivary nuclei in another section.

With these two planes established—the lateral by the fissures assumed to be straight and the transverse by the occurrence at the same levels of the limits of corresponding nuclei—the definite establishment of an antero-

posterior plane was to be decided. It was thought that possibly there might be found a constant relationship between some definite point in the tegmentum and a point in the basilar portion of the brain-stem. Many points in several sectioned brain-stems were tested for this desired constancy in relationship, but no two points could be established which maintained the same relative positions in different brains. For the determination of this antero-posterior plane, which in sections of the adult lower brain-stem is least important of all, the use of the external form and of the floor of the fourth ventricle was necessary.

The wax plates were cut out along the lines indicating the external form of the section and were then piled with reference to the three planes, the whole giving a very accurate reproduction of the external form of the brain-stem in its lower portion. Definite points were made on successive plates to give the relationship of plate to plate and reconstruction of the nuclear masses was begun. The portions of the plate to be modeled were preserved, together with the points to show the relationship to the adjoining plates, and the remainder of the plate was cut away. The relations of the individual nuclear masses to the whole were preserved by means of wax bridges left in the original plate, and these bridges were cut away as soon as the nuclear mass was fixed in its position.

As far as possible, no fusion of wax plates was resorted to until a considerable number of plates had been piled together. The object of this procedure was to avoid the introduction of chance variations in the plates, as will necessarily occur if the fusion be done as each plate is added. Owing to the complexity of the inferior olivary nucleus, such fusion had to be done as each plate was added, but it is felt that additional information regarding its complexity is probably added in this one case.

The brain-stem from which the sections used in this reconstruction were cut was embedded in celloidin in several individual blocks. In the portion of the series here involved three blocks were concerned and compensation for the tissue lost in the transition from the first to the second and from the second to the third blocks had to be made. The second block was somewhat distorted and to make the plates representing the second block coincide with those of the first the magnification of 15 diameters had to be changed in both antero-posterior and lateral dimensions. With this correction applied, the plates of the third block with the uniform enlargements of 15 times fitted exactly the resultant model. The corrections for loss of tissue amounted to 2 plates on one side between sections 345 and 350; in the second instance to 1½ plates between sections 700 and 705.

In the drawings of the completed reconstruction, the representations have been made from a single viewpoint, in perspective, which is taken from the level of section 600. This difference between perspective and geometric representation results in some foreshortening, which is most marked in the spinal segment of the model.

DESCRIPTION OF TRANSITIONS FROM CORD TO MEDULLA.

THE ANTERIOR MOTOR COLUMN.

The anterior motor column has been reconstructed in this model from the upper cervical region to the point where it blends with the formatio reticularis of the medulla. On the left side of the model (figure 2) the separation of the anterior column (*mc*) from the tegmental gray matter has been shown, but on the right side the fine extensions of nuclear material from the tegmental portion to the column have been included (cf. two sides of figure 9), so that the course of the pyramids into the lateral columns in the cord is not given. The morphology resulting from the modeling on the right side will be discussed under the subdivision of the substantia grisea centralis and the formatio reticularis. The present portion of this communication treats only of the morphology of the isolated anterior column. The term "anterior column" will be used throughout to designate the collection of motor cells in the anterior portion of the gray matter of the spinal cord (*mc*, figure 8); the term "anterior horn" will not be used, as it does not represent the continuous character of the cell-collection.

Figure 8 shows the typical transverse section of the upper cervical cord. In this the anterior column appears on section as an irregularly triangular mass of motor cells and supporting tissue. The anterior column (*mc*), as modeled, is shown in figures 1, 2, and 4, dealing here with the left side of the reconstruction. It does not present any well-defined surfaces for examination, but is probably best described from the lateral, ventral, and mesial views a shown in the drawings. Roughly, it may be divided here into the cervical portion, the portion isolated from the gray matter by the pyramids, and the superior portion, in which the anterior column fuses with the formatio reticularis.

When viewed from the lateral surface (figure 2), the anterior column in its cervical portion exhibits a somewhat rounded ventro-lateral surface, which is sharply defined dorsally, but curves gradually around the ventral side. Its dorsal margin is a fairly straight, slightly irregular projection. Just ventral to this is a small, elevated ridge which runs cephalo-caudally throughout this portion. Ventral to this ridge is a very shallow longitudinal depression, anterior to which the rounding of the surface ventrally occurs. The character of the column changes considerably as the region of its separation by the pyramids is reached (figure 9). The dorsal margin, at the caudal end of this decussatio pyramidum (cf. figure 2), is marked by irregularities, the most caudal of which becomes a well-defined dorsal spur. This is followed, cephalad, by a convex sheet-like projection dorsally, superior to which is a shallow ventral depression. The cephalic border of this gradually inclines dorsally and then runs sharply cephalo-caudally to the superior limit of the decussation. The lateral ridge, noted in the cervical portion of

the column, becomes ill-defined and irregular in the caudal portion of the decussation, but in its superior portion it is accentuated as a laterally projecting thin sheet of cellular tissue. This curves slightly dorsally, but shows a marked ventral curving in the region just above the pyramids. The shallow depression of the cervical portion of this surface becomes converted into a definite furrow in the caudal half of the decussation; superior to this, it is lacking and the surface ventral to the lateral ridge is smooth.

Superior to the decussatio pyramidum, the anterior column loses much of its character. Its dorsal surface merges with the cephalo-ventral slope of the formatio reticularis as this latter becomes prolonged ventrally in the form of a ground substance fairly free from fiber tracts. This is illustrated by the fusion, in figure 2, of uncolored formatio reticularis with the red motor column. This portion of the formatio, with its comparative freedom from fiber tracts and its deeper staining qualities with carmine, projects laterally just ventrally to the substantia gelatinosa. From this point, it turns sharply ventrally as an irregularly corrugated surface. It merges caudally with the dorsal surface of the anterior column, first as a small bridge of typical tissue, then intermits cephalad, to be connected by a second bridge of gray matter. Superior to this second intermission is the continuous connection of formatio with the vanishing anterior column. Coincident with the second bridge of the formatio reticularis occurs a marked lateral projection of the formatio, superior to which is a marked concavity in its surface. The lateral ridge of this surface, which was so prominent in the superior portion of the pyramidal crossing, curves sharply ventrally, cephalad to the pyramid decussation, and then loses its character on the lateral surface between the two bridges of formatio reticularis. Just caudal to its cephalic termination a division of the anterior column into two parallel masses is suggested from this surface (figure 1). The motor cells are gradually lost in the upper part of this region and as the interior column becomes fused with formatio reticularis the motor cells disappear.

Inspection of the ventral view of the model (figure 1) shows the anterior column on the left pursuing an almost direct cephalo-caudal direction, with a slight cephalo-lateral deflection. The anterior column on the right side shows a marked bowing laterally in the region of the decussatio pyramidum. The left anterior column is broader in the cervical region than in the two superior portions; in its caudal portion the ventral side is rounder, while in the region of the pyramidal crossing it is flattened and narrowed and abruptly marked off from the lateral and mesial surfaces. In the portion cephalic to the superior limit of the decussation the anterior column shows a division into two masses of motor cells. The more mesial of these two columns continues the direction of the primary column. These two cell-columns are discrete and can be traced cephalad for some distance. The motor cells gradually disappear and the two columns merge in that part of the formatio, comparatively free from fibers, which projects ventrally. Such

a division of the anterior horn into two cell-columns suggests the embryological continuation of the anterior columns cephalad, to form the mesial and lateral groups of motor nuclei.

From the mesial view (figure 4) the anterior column shows, in its cervical portion, a smooth mesial surface, which gradually merges into the central gray matter of the cord. Throughout the extent of the decussatio pyramidum, the ventral portion of the mesial surface is smooth, but the dorsal portion is roughened by numerous dorsal and mesial spurs. Above the crossing, the mesial surface fuses gradually into the ventrally projecting masses of formatio reticularis. The formatio shows a fairly smooth surface, interrupted by a fiber tract in the caudal portion. This intermission of the gray matter of the formatio on the mesial surface corresponds to the intermission on the lateral surface, so that on mesial view the gray matter of the formatio shows a hole through it. This ventrally projecting formatio really consists of two plates, a lateral and a mesial, which fuse above and below, but in their middle contain a considerable fiber tract. The plates are practically fiber-free.

The cervical portion of the anterior column and the part ventral to the decussation exhibit a dorsal surface. In the cervical cord the dorsal lateral border is sharply converted into an irregular concavity which forms the dorsal surfaces throughout this extent (figure 8). This is continued mesially into a well-defined lateral ridge which projects outward from the central gray matter. In the region of the decussation of the pyramids the dorsal surface is marked by irregularities and shows many dorsal and mesial spurs projecting between the crossing bundles of the pyramids. This surface is eliminated as the column fuses with the formatio reticularis.

As will be seen in figure 2, the anterior column, after its fusion with the formatio reticularis, is abruptly and arbitrarily ended in the model. This was done for several purposes, particularly as it was thought advisable to show the olivary complex completely separated from the formatio reticularis on the one side (left) and developing out of it on the other (right side of model, figure 1).

SUBSTANTIA GRISEA CENTRALIS AND FORMATIO RETICULARIS.

The two sides of this model were reconstructed for different purposes, so that on the right side the reconstruction should deal only with the unseparated masses of gray matter, outlines being drawn around the extreme portions of the gray matter present in the series of transverse sections. Hence, on this right side, the substantia grisea centralis, that indifferent mass of gray matter about the central canal of the spinal cord (figures 8 and 9), is modeled together with the extreme portions, such as the nucleus fasciculi gracilis, the nucleus fasciculi cuneati, the substantia gelatinosa (figures 10 and 11), etc. Tracing this gray matter about the canal cephalad, we find it merging with the formatio reticularis of the medulla and pons, but

this fusion is not well shown in the model because of the fact that the formatio reticularis is surrounded by the nuclei which separate the formatio from the fiber tracts which bound the brain-stem in this portion. The central gray matter of the cord will here be described as it goes cephalad to merge with the medullary formatio reticularis, and the extreme mass of gray matter of the cord will be briefly commented upon.

The typical cross-section of the central gray matter of the upper cervical cord is shown in figure 8. Here it can be seen to consist of a central body, surrounding the central canal, and of two arms on each side projecting from the ventral and dorsal angles of the lateral surface. Dorsally, the arm is long and curving (*cg* in figure 3), constituting the posterior column with its substantia gelatinosa. In the mid-line this arm is elevated into a very slight dorsal ridge. The lateral surface of the central gray matter shows a concavity extending upward into the decussatio pyramidum; this concave surface results from the curve of the posterior arms of the central gray matter and the mesial projection of the anterior columns. The floor of this depression is very smooth except near its ventral termination in the anterior column; here the surface is raised into a definite lateral ridge. Ventral to this ridge, the surface slopes rapidly into the dorsal surface of the anterior column. Anteriorly the body is characterized by a slight mid-line ventral ridge, on each side of which are concave surfaces.

The central gray matter is considerably affected by the decussatio pyramidum. The most striking of these changes consists in the breaking up of the anterior arm of the gray matter by the obliquely coursing pyramidal fibers (figure 9). On the left side of the model, as shown in various figures, the reconstruction was limited to the solid mass of the anterior column and to the undisturbed portion of the central gray matter. Inspection of figures 2 and 4 shows well the resulting morphological changes in the central gray matter. The ventral border is turned dorsally in a gradual convexity, but with a more rapid dorsal deflection than the central canal exhibits (figure 4). This figure also records the marked irregular projections of the ventral border. The lateral surface of this central gray matter shows in its ventral portion no lateral curving because of the separation of the anterior column, but the dorsal convexity is continued to the ventral margin in the mid-line. This ventro-lateral surface which results is marked by many irregular projections, most of them short and thick. At a point opposite the caudal end of the nucleus fasciculi gracilis (figure 2), the central gray matter shows its first merging into formatio reticularis, for here it is that the peculiar fiber-free portion of the formatio begins to project ventro-laterally to connect finally with the anterior column. This mass is separated from the substantia gelatinosa by a very deep and narrow fissure which curves inwardly, following the ventral curve of the substantia gelatinosa (figures 1 and 2). Mesially, these projections are separated from the ventral projection of the central gray matter by a deep, and somewhat wide, irregular

furrow. A more detailed description of these projections has been given in the subdivision describing the anterior column.

On the right side of this model, the spurs of nuclear material between the fiber bundles and the outer limits of the gray matter have been modeled. This results in a slight fenestra in the wax, marking the crossing of the pyramids, while the great area of the decussation is occupied by the network of nuclear material which lies between the fiber bundles. Such a picture of the network is shown in figure 9. When this right side is viewed laterally, the most striking feature is the fulness of this surface as compared with the left. Following the dorsal margin of the anterior column cephalad, it is seen to extend dorsally in the caudal portion of the pyramidal crossing by a series of step-like dorsal projections. It very soon fuses with the formatio reticularis ventral to the substantia gelatinosa. From this point cephalad, the extreme lateral wall of gray matter is solid, and exhibits certain characteristics dependent upon the level considered. The mesial surface of this dorsal projection from the ventral horn is very rough and irregular, marked by the outlines of the coursing pyramidal fibers (figure 9). Inspected from the ventral surface (figure 1), the right side shows marked irregularities in its dorsal concavity in the region of the decussation, as well as marked lateral bowing of the anterior column in this region. Above the decussatio pyramidum, the anterior portion of this gray matter of the formatio reticularis becomes markedly widened transversely. From the marked ventromesial border, the mesial surface slopes dorsally toward the mid-line without irregularities. The mid-line ventral projection is not marked.

As soon as the anterior column becomes united to the ventral surface of the formatio reticularis, its lateral surface becomes marked by irregularities. A poorly defined ridge with a sharp dorsal border continues the line of the dorsal margin of the anterior column for a short distance cephalad. Dorsal to this are two short irregular ridges which deviate to the substantia gelatinosa. Just above the ventral of these three ridges is the rounded caudal shoulder of an elevation which runs cephalad, to expand suddenly as the nucleus olivaris inferior develops in its midst (figure 1). A short distance caudal to the oliva, between this eminence and the substantia gelatinosa, is a well-defined lateral ridge, broad and smooth, which is traced cephalad to a point slightly caudal to the cochlear nucleus. Behind this eminence are the irregularities of the nucleus of Blumenau and around on the dorso-lateral surface is the smooth plate of gray matter which leads posteriorly into the tela choroidea inferior (figure 3).

The relations of the nucleus olivaris inferior to the formatio reticularis are of interest. The anterior column, after merging with the formatio reticularis and losing its motor cells, becomes increased in the transverse and dorso-ventral diameters (figure 1), showing a sudden enlargement just caudal to the nucleus olivaris inferior. On the mesial surface of this enlargement the caudal end of the nucleus olivaris accessorius medialis develops.

As soon as this appears, the enlargement shows a cupping for the caudal pole of the inferior olive and the formatio reticularis recedes from it to form a ventral surface at some distance posterior to the dorsal leaf of the olive. This ventral surface is smooth in the main, with a slight curvature, so that it faces for the most part mesially as well as ventrally. The nucleus olivaris accessorius dorsalis lies ventral to it, separated by a small series of fiber bundles. The mesial edge of this surface is very irregular in its upper two-thirds, while its lower one-third is in intimate relation with the dorsal margin of the nucleus olivaris accessorius medialis. Above the superior mesial angle of the dorsal accessory olive is an irregular ventral spur. The lateral border of this ventral surface of the formatio reticularis in the olivary region shows a gentle concavity which includes the olive. It is continued laterally into a roughened ventro-lateral plate which exhibits a very irregular dorsal border, projecting laterally over the lateral surface of the main mass of gray matter.

The mesial surface of this olivary portion, bordering laterally the stratum interolivare, is fairly smooth, showing many gentle eminences.

At the superior end of the inferior olivary nucleus the lateral wall is marked by the masses of gray matter projecting out from the vestibular nucleus along the entering vestibular nerve. This surface is continued upward into a mass of gray matter lying dorsal to the vestibular nuclei—the dorsal projections of the medial and superior portion (figure 13). On dorsal view (figure 3) these masses are shown cut off abruptly on the right side of the model. Continuing cephalad, the projections are seen to merge into the dorso-lateral plates of the superior vestibular and of the trigeminal nuclei.

The extreme lateral surface above the vestibular complex is marked by the irregular bulbous swelling of the sensory portion of the trigeminal nucleus. Ventral to this the wall is continued irregularly into the dorsally projecting lateral wall of the pons. The mesial surface of this portion of the general gray matter is smooth and approximates the line of the raphe, as the median fillet assumes the transverse direction and divides the pontine nuclei from the formatio reticularis.

The ventral surface of the formatio reticularis, in the region cephalic to the superior pole of the nucleus olivaris inferior, shows a very striking ventral projection. This is seen in part in figure 13. As the superior pole of the olive recedes and vanishes, the formatio reticularis sends ventrally a long, narrow, mesial spur and a shorter lateral spur (figure 13); these are well defined and are separated by longitudinally coursing fibers. These projections surround somewhat and join with the cells of the pontine nuclei. The mesial of the two masses does not extend cephalad for a very great distance, as it is abruptly eliminated by the changing of the medial lemniscus to its transverse position in the cephalic portion of the pons. The shorter, thicker, lateral projection continues to carry the formatio reticularis tissue

toward the pontine nuclei, until the lateral wall of the pons projects far dorsally. Both of these projections are very irregular and are cut by fiber bundles coursing through them and by spurs and fissures on their surfaces.

As the lemniscus medialis changes its long axis to a transverse position, the character of the ventral wall of the formatio reticularis changes. The mesial ventral projection is suddenly discontinued, but the deep dorsal fissure between the two projections continues almost to the cephalic border of the model. This ventral surface of the formatio, lying dorsal to the lemniscus medialis, is roughened by slight eminences and shallow groovings. Mesially it is encroached upon by the nucleus reticularis tegmenti pontis.

THE INDIVIDUAL MASSES OF GRAY MATTER.

NUCLEUS FASCICULI GRACILIS.

From its inferior end, just caudal to the lower extremity of the decussatio pyramidum, the nucleus fasciculi gracilis extends as a continuous nuclear mass to the inferior end of the nucleus vestibularis medialis—a point on the same level with the mid-point of the nucleus alæ cinereæ. It measures in the longitudinal direction 14.4 millimeters. The whole extent of the nucleus (*gr*) is shown in figure 3, a dorsal view, while figure 4 gives the mesial view. Figure 9, a characteristic transverse section through the decussation of the pyramids, shows the extent and characteristics of the nucleus in its caudal half, while figure 10 gives a transverse section through its broader and larger cephalic half.

In its caudal portion the nucleus lies in the midst of the fiber bundles of the fasciculus gracilis, but the fasciculus becomes smaller above and the nucleus correspondingly larger, so that this nuclear mass occupies the whole of the mesial dorsal segment of the medulla (figures 3 and 10). On the mesial surface the dorsal longitudinal fissure is in close approximation in the lower two-thirds of the nucleus, but in the cephalic portion the mesial surface is in relation particularly to the caudal half of the nucleus alæ cinereæ. Lateral to this gracile nuclear mass are the fibers of the fasciculus cuneatus for the caudal five-sixths of its extent, but in its more cephalic portion the cell-mass of the nucleus fasciculi cuneati is directly lateral to it. Ventral to the nucleus lies the central gray matter of the cord in its lower two-thirds; in the cephalic one-third are the nucleus alæ cinereæ and the fasciculus solitarius with its accompanying lateral nuclear mass. These relations are brought out in the transverse sections already referred to and in the figures showing the dorsal and mesial surfaces of the model.

The dorsal aspect of the nucleus fasciculi gracilis, when reconstructed, shows as a long mass, with the caudal half narrow and gracile while the cephalic half broadens out in the clava (figure 3). This increase in the transverse diameter of the nucleus is rather sudden and occurs at the cephalic limit of the decussatio pyramidum. The most caudal portion of the nucleus

from dorsal view shows as a rather smooth, narrow column in close relation to the dorsal fissure. The nucleus in its caudal portions has a poorly defined mesial surface and the nuclear material extends practically to the dorsal fissure, even though the main characteristic nuclear mass, on superficial inspection, seems to end at some distance lateral to the furrow. Hence, on reconstruction, the nuclear columns of both sides, representing the two nuclei, lie in fairly close approximation in the mid-dorsal line. This mesial dorsal edge of the two nuclei shows considerable curving, a phenomenon due to the peculiarities in the nuclear formation, as the dorsal longitudinal fissure was reconstructed as a straight line and served as one of the main guides against lateral deviation. At a level with the caudal extremity of the nucleus fasciculi cuneati, the dorsal surface of the nucleus fasciculi gracilis shows three dorsal spurs (figures 3 and 9). The most lateral of these, bounded mesially by a deep furrow, is short and rather thin, exhibiting a tendency to fold in a gentle curve toward the mid-line. The middle of the spurs projects dorsally more strikingly than does the lateral, as shown in figure 2. This middle spur arises gently from the dorsal portion of the nucleus caudal to the inferior end of the cuneate cell-mass and only slowly assumes the character of a sharp spur. At its cephalic end it curves rather abruptly mesially and loses its character in a broader mesial slope. The mesial of these caudal dorsal spurs is very poorly defined, being constituted of a series of imperfectly differentiated notches, as shown in figure 3. This mesial spur can be traced cephalad somewhat further than the other two; it ends in a small rounded knob of nuclear material. The points of cephalic termination of these three spurs constitute a fairly straight line, which runs from the lateral spur mesially and cephalad. The lateral of these spurs, after ending, may be considered to begin a short distance cephalad to its termination, as a fairly well-defined ridge which continues upward to end in bulbous dilatation over the broader cephalic half of the nucleus. Lateral to the superior portion of this ridge is a deep furrow, on the outer side of which is a small dorsal spur. The middle of the inferior group of dorsal spurs, after a slight interruption, is continued cephalad as a small, pyramidal projection which ends at about the same level with the lateral spur. Mesially the third spur is not made out. In the corresponding place, however, at the point of cephalic termination of the other spurs, occur two small knob-like projections, both mesial to the middle spur.

In the middle of these upper dorsal corrugations, the nucleus fasciculi gracilis widens out rather abruptly. Above their cephalic terminations, occurs a slight transverse depression, cephalic to which the nucleus presents a smooth dorsal surface. It widens very slowly in its superior half, to reach its greatest transverse diameter at a level with the calamus scriptorius. Here the nucleus shows as a marked and prominent mesial shoulder, corresponding to the widening out of the spinal canal into the fourth ventricle (figure 3). Above this point the mesial dorsal edge of the nucleus rapidly

recedes laterally in a lateral convexity. Dorsal to this extreme mesial edge is a second angle in the nucleus, corresponding to the point of attachment of the inferior velum. This line curves around to terminate at the junction of the mesial vestibular nucleus and the nucleus of the fasciculus cuneatus. Lateral to the line of attachment of the velum is a broad, curving, and smooth surface, directly underlying the surface form. This plate is, at its caudal extremity, almost entirely composed of the nucleus fasciculi gracilis, but as it passes cephalad the nucleus fasciculi cuneati gradually encroaches upon it, occupying it entirely at the cephalic limit of the gracile nucleus just below the median vestibular nucleus. This encroachment determines the lateral dorsal termination of the nucleus fasciculi gracilis.

The mesial view (figure 4) of the nucleus fasciculi gracilis shows the long transverse axis of the nucleus to be dorso-ventral in direction. Caudally, the anterior part of the nucleus does not extend to the so-called central gray matter. The ventral limit of the nucleus soon approaches this gray matter and extends cephalad in a gradual curve to the opening of the fourth ventricle. The mesial surface of the gray matter of the gracile nucleus lies slightly lateral to the central canal and to the dorsal longitudinal fissure (figure 9). It shows slight lateral depressions and projections, corresponding to the curving of the mesial limits as seen on dorsal view. The most marked of these lateral depressions occurs about the level of the sudden widening out of the upper half of the nucleus. The dorsal limit of the nucleus, as seen on mesial view, shows the irregularities due to the dorsal spurs already described. These peculiarities of the nucleus are excellently shown in the mesial view of the model (figure 4). The ventral limit of the nucleus in its uppermost portion follows the line of the tractus solitarius, curving rather quickly dorsally, as the nucleus of the tractus becomes associated with the descending vestibular mass. The ventral edge then curves dorsally and caudally to meet the dorsal and cephalic limit of the nucleus. Mesially, then, the gracile nucleus extends in a slight projection cephalad to its dorsal limit, showing medially a triangular projection with the apex cephalad between the vestibular nucleus and the nucleus tractus solitarii.

The ventral limit of the nucleus fasciculi gracilis is well defined throughout. In the caudal portion the nuclear characteristics permit an easy differentiation from the gray matter about the central canal. In the more cephalic regions the bundles of the fibræ arciformes internæ are taken as the mesial and ventral terminations of the nucleus (figure 10). The ventral surface in the caudal parts is almost transverse, but in the more cephalic portions the curve of the internal arcuate fibers forms a curving surface which looks not only ventrally but also laterally.

The lateral surface of the nucleus fasciculi gracilis is seen in figure 2, which shows the irregular dorsal outline in the lower half, the marked bulging of the upper half, and in part the relations to the cuneate nucleus. The lateral surface of the lower part of the nucleus really slopes dorsally and

laterally from the central gray matter. The ventral margin lies in a straight line, is straight along the central gray matter for the caudal one-third of the nucleus; then it forms, in the deep groove filled with fibers of the fasciculus cuneatus, between the gracile and cuneate nuclei, another straight line which continues to the point where the two nuclei are closely related on the lateral plate, above mentioned, as the nucleus of fasciculus gracilis curves medially to terminate.

Miss Sabin, in her reconstruction of the medulla and mid-brain of the new-born, considers the gracile nucleus as a separate entity only in the caudal portions, but as fusing above with the cuneate nucleus to form a central nuclear mass—a nucleus of the dorsal funiculus, which she believes to be wholly a nucleus fasciculi cuneati. The nucleus of Blumenau she considers as also contributing to this nuclear complex. While such a fusion of the cephalic portion of the gracile nucleus with the cuneate nucleus could be assumed, study of the serial sections in the adult has led to the conclusion that the nucleus fasciculi gracilis can be divided from the nucleus fasciculi cuneati. These limits of the nucleus fasciculi gracilis have already been described for the adult. Miss Sabin's description of the morphology of the nucleus fasciculi gracilis is somewhat inadequate, so that a close comparison of the shape of the nucleus in the new-born and adult can not be made.

NUCLEUS FASCICULI CUNEATI.

Beginning caudally somewhat superiorly to the mid-point of the decussatio pyramidum and extending cephalad to the caudal limit of the cochlear nucleus, the nucleus fasciculi cuneati presents a varied and irregular morphology. In its longitudinal diameter the nucleus measures in this adult medulla 14.4 millimeters; the other diameters are not given, on account of their marked variation at different levels. In this study, account is taken of the so-called nucleus cuneatus lateralis or the nucleus of Blumenau (1891)—that collection of well-defined large cells which overlies laterally the main cuneate cell-mass. In the reconstruction it was found that these collections of apparently isolated cells lying in the fibers of the fasciculus cuneatus were connected in every case with the main nucleus, so that a division of the two nuclei could not be made except on histological grounds. Whether such a division has any functional or neurological importance can not be ascertained by the means of study used in this reconstruction. The two portions of the nucleus have been modeled together and will be described as far as possible as a single nucleus fasciculi cuneati. As mentioned in the description of the nucleus fasciculi gracilis, Miss Sabin included together the cephalic portions of the nuclei of the dorsal funiculus; this inclusion of the two in a single cephalic enlargement we do not consider now justified. The nucleus fasciculi cuneati is easily differentiated from its neighboring nucleus of the fasciculus gracilis.

Dorsal to the nucleus fasciculi cuneati lies the fasciculus cuneatus, in whose fiber bundles occur the cell-collections of the nucleus of Blumenau (figures 9 and 10). In the cephalic portion of the nucleus the fasciculus comes to lie almost lateral to it (figure 11). The nucleus fasciculi gracilis and the nucleus vestibularis, pars descendens, lie mesial to the nucleus (figures 3, 10, and 11). Lateral to the nucleus and in the cephalic half, ventro-lateral, occurs the substantia gelatinosa of the fifth nerve. Ventrally the nucleus is in relation with the central gray matter and with the formatio reticularis; from the latter it is separated by the curving fibræ arciformes internæ. In its superior portion it is in ventral relation with the descending portion of the vestibular nucleus, as the latter pushes the nucleus fasciculi cuneati dorsally and laterally to its rather abrupt cephalic termination. These relationships are for the most part shown in figures 2 and 3 (*cu*).

The nucleus may be described as an irregular wedge-shaped cell-mass with corrugated dorsal and lateral surfaces and a small ventro-mesial convexity. The caudal portion of the nucleus is best seen on dorsal view (figure 3) and the cephalic half on lateral view (figure 2). This change in the direction which the exposed portion of the nucleus takes is probably to be accounted for by the more lateral position which the nucleus assumes as the fourth ventricle widens out. It is also accounted for in part by the increased dorso-ventral diameter of the nucleus in the region of the lower end of the fourth ventricle—a phenomenon marked also by the ventral curving of the substantia gelatinosa in this part (figure 2).

When viewed tangentially to its superficial or exposed surface (resulting from the removal of the fibers of the fasciculus cuneatus), the nucleus is seen to begin caudally as a blunted extremity (figure 3) on the dorsal surface of the substantia grisea centralis and to widen gradually to its point of greatest width at a level with the caudal end of the nucleus vestibularis medialis. Above this, the nucleus narrows, due to the dorsal deflection of its lateral ventral border, until it terminates above in an abrupt convexity, where the descending portion of the vestibular nucleus becomes superficial beneath the corpus restiforme.

The most caudal portion of the nucleus consists of a small dorsal ridge with somewhat corrugated slopes. On cross-section (figure 9) near its most caudal termination, the nucleus appears triangular with a slightly curving base on the central gray matter. The dorsal ridge of this main nucleus of the cuneate fasciculus can be traced in figure 3 throughout the caudal half of the nucleus, above which point it is covered by and merges with the more irregular nucleus of Blumenau. This dorsal ridge of this caudal half of the nucleus deviates laterally, soon after its origin, by the widening of the nucleus fasciculi gracilis, but it soon assumes again and continues its straight cephalo-caudal direction to the point at which it vanishes ventrally in the middle of the nucleus. The extent of the nuclear material included between the sloping sides which unite to form this median dorsal ridge increases somewhat as this portion of the nucleus runs cephalad.

About in the middle of this dorsal ridge, in the caudal half of the nucleus, its lateral slope becomes marked by irregularities in the form of slight furrows and ridges. As one passes cephalad, these soon take shape in a marked dorso-lateral projection which continues superiorly as a constituent portion of the nucleus of Blumenau. This projection, in its lower portion, forms a solid rectangular spur, but above, in its connection with the main cell-mass, it becomes narrowed into a small pedicle with a broad, thin, lateral plate lying in the midst of the fibers. This column can be traced cephalad to the middle of the whole nuclear mass; in its upper portion it turns somewhat mesially, ending in a column of cells arising from its dorso-mesial angle in the cephalic termination (figure 2). This new column rapidly connects with an irregular bridge of cells, which covers the lateral aspect of the dorsal ridge and runs to the mesial portion of the whole nucleus as it begins to assume the dorsal plate with the nucleus fasciculi gracilis (figure 3). Just lateral to this first dorso-lateral ridge is a projection which begins caudally somewhat cephalad to the first. This is in close relation to the substantia gelatinosa (figure 2). Beginning below as a thin rectangular mass of cells, this column rapidly widens into a rather broad lateral plate with a small pedicle of cells connecting it with the main underlying nucleus (figure 10). This plate marks the lateral limits of the nucleus and is shown throughout its extent in figure 2. Soon after its caudal origin it exhibits a marked dorsal notch; then it overlies laterally, in a ventral projection, the substantia gelatinosa. Coursing dorsally and cephalad from this ventral projection, it finally loses its character in the broad, smooth, cephalic termination of this lateral surface. Connected with this lateral plate, just above its ventral projection, is an irregular triangle of cells elevated somewhat above the main cell-mass (figure 2). The apex of this joins the lateral plate, while its base lies just beneath (ventral) the lateral edge of the dorsal plate. Its cephalic margin is marked by a furrow on the ventral side and by three irregular spurs on the dorsal; the furrow and projection mark off the triangle from the smooth upper portion. The lateral surface of this triangle is marked by a prominent gradual eminence and below by a deep furrow. A sharp depression also occurs on its surface. Caudally, the side of the triangle is marked by a deep dorsal and a deeper, sharper ventral furrow, between which is a median ridge which projects ventrally and somewhat caudally, to terminate near the lateral plate. In the ventral fissure just mentioned, occur irregular lateral spurs and ridges, some running up to the median ridge as it goes to terminate in a shallow groove marking it off from the lateral plate. The caudal limit of the dorsal furrow, which delimits the lower side of the triangle, is constituted by the transverse bridge of cells, already mentioned as continuing the first dorso-lateral projection to the dorsal plate.

This dorsal plate, the caudal mesial part of which the nucleus fasciculi gracilis occupies, is shown both in figures 2 and 3. It is a smooth curving

plate, lying superficially beneath the surface. Caudally it is wholly composed of gracile nucleus (figure 10), but at the level of the transverse bridge of cells, in the cuneate nucleus, the plate begins to be composed of the nucleus fasciculi cuneati. At the caudal limit of the nucleus vestibularis medialis (figure 3) the whole dorsal plate is occupied by cuneate cells. Then, as the descending portion of the vestibular nerve develops, the dorsal plate recedes laterally in a lateral convexity to approach mesially and terminate ventrally to the lateral portion of the nucleus vestibularis medialis. The lateral margin of this dorsal plate is quite irregular (figure 3) and overhangs (*i. e.*, is dorsal to) the base of the lateral surface triangle.

Above the superior transverse limit of the lateral triangle of the nucleus fasciculi cuneati is the cephalic field of the lateral surface of the nucleus. This is a fairly smooth area with a gradually convex upper border made by the cells accompanying the descending vestibular root as they become superficial. Mesially the superior termination curves ventrally to the lateral portion of the nucleus vestibularis medialis, to merge with the cephalic end of the dorsal plate.

The ventro-lateral limit of the nucleus fasciculi cuneati, as soon as the nucleus reaches its average dimensions, is easily distinguished, on histological grounds, from the adjoining substantia gelatinosa (figures 10 and 11); it forms a fairly straight line following the dorso-mesial edge of the substantia (figure 2). Mesially the nucleus fasciculi cuneati in its caudal half is well separated from the nucleus of the fasciculus gracilis by dense fiber bundles. In the cephalic portion of the gracile nucleus the differentiation of the two nuclei is not as easy, but is possible. This line of separation is curved, following the direction of the fibers coursing between the nuclear masses. Mesially the nucleus fasciculi cuneati shows a curving smooth surface which looks laterally and mesially and moves somewhat dorsally as it develops cephalad. Its convexity follows the curving internal arcuate fibers. The mesial ventral border, separating from the nucleus fasciculi gracilis, lies just dorsal to the nucleus tractus solitarii (cf. figures 10 and 11). Cephalad the mesial border is abruptly pushed laterally by the developing pars descendens of the vestibular complex; its mesial border, however, maintains its convexity until it terminates superficially in the convex cephalic border of the smooth superior lateral field.

RELATION OF NUCLEI TO FLOOR OF FOURTH VENTRICLE.

The correlation of the anatomical markings of the floor of the fourth ventricle with the underlying nuclear masses was first well worked out by Streeter (1903). In this reconstruction, it has been attempted to show this relationship in a slightly different manner than demonstrated by Streeter. The work on this adult brain-stem was rendered less accurate by the fact that no drawings or photographs of the external form and of the floor of the

fourth ventricle were made before sectioning. This, of course, gave some difficulty in securing accuracy in the piling of the wax plates, but the errors were to a large extent overcome by reference to the surface and ventricular form which best coincided with the majority of the drawings of medullæ given by Retzius. Yet in such cases one is inevitably impressed by the extreme individual variations in the anatomy of floor which are present in a series of brain-stems. Hence, in this reconstruction, not so much attention can be paid to the smaller features of the anatomy of the floor of the ventricle, but the larger structures are accurately placed and the relationship of the nuclear masses to these is of importance and value. The floor of the fourth ventricle was modeled on the right side of the reconstruction, while on the left side the several nuclei alone were fashioned, and by comparison of the two sides the relationship is apparent. The two sides with their nuclear masses in relation are well shown in figure 3. No attempt will be made to discuss here the surface markings, as nothing in the material used has value in such a discussion, but Streeter's division of the floor will be followed. Most important in this study is the comparison of the limits of nuclei as found by Streeter.

Just lateral to the median line in the caudal half of the ventricular floor occurs a slight elevation, oval in outline, representing the cephalic half of the nucleus nervi hypoglossi (figures 3 and 11). This is designated by Streeter as the eminentia hypoglossi and corresponds to the eminentia medialis trigoni of Retzius. In the lateral angle of this small oval occurs a dorsal bulging coincident with the most dorsal projection of the twelfth nucleus, as shown in figure 3. Above this, the nucleus nervi hypoglossi turns toward the mid-line, terminating at about the line of transverse division of the ventricle (in general, corresponding to a line drawn between the caudal margins of the lateral recesses). The mesial surface of the nucleus nervi hypoglossi alone contributes to this elevation, as the lateral dorsal surfaces of this nuclear mass are entirely covered by the nucleus alæ cinereæ in the caudal portion (figure 11) and by the nucleus intercalatus in the cephalic half. The cephalic limit of the hypoglossal nucleus in this reconstruction coincides exactly with that occurring in Streeter's diagram of the ventricular floor.

Directly above the area described is a small, rather poorly defined elevation overlying the nucleus funiculi teretis. In this brain-stem, as mentioned in its description, the nucleus funiculi teretis is very short and, perhaps in consequence of this, the elevation is very ill-defined. The eminence is further affected by the occurrence of the striæ medullares; in this adult brain-stem these striæ are almost lacking. Streeter pictures the nucleus funiculi teretis as extending from just caudal to the cephalic end of the nucleus nervi hypoglossi to a point slightly superior to the cephalic ending of the nucleus intercalatus. The extent of the modeled portion of the nucleus is easily seen in figure 3. It begins cephalad to the nucleus of

the hypoglossal nerve and extends but a short distance upward, always median to the nucleus intercalatus.

Lateral to the nuclei of the hypoglossal nerve and of the funiculus teres lies the nucleus intercalatus. This is represented on the surface by a rather elongated diamond-shaped elevation lying lateral to the eminentia hypoglossi and the eminentia of the nucleus funiculi teretis, and mesial and cephalic to the ala cinerea. While the area plumiformis extends caudally to the calamus scriptorius, as pointed out by Retzius and Streeter, the nucleus intercalatus shows its caudal end at the extreme dorsal projection of the area hypoglossi, extending from this point cephalad to the nucleus nervi abducentis. Streeter pictures the nucleus intercalatus as ending in the area of the striæ medullares, in which region the area plumiformis ends, but in this adult brain-stem the nucleus extends considerably farther cephalad. The cephalic portion of the nucleus then extends beyond the superior limit of this area plumiformis.

Situated laterally to the nucleus nervi hypoglossi and to the nucleus intercalatus, and mesially to the nucleus fasciculi gracilis and nucleus nervi vestibularis, lies the ventricular one-third of the nucleus alæ cinereæ (figures 3 and 11). This is represented on the ventricular floor by the fovea vagi or ala cinerea, the middle of the three original triangles in the caudal half of the ventricle. This area shows a marked depression in the ventricular floor in its superior portion, corresponding to the place where the nucleus alæ cinereæ dips ventrally to the vestibular nucleus and nucleus intercalatus. Caudally, the area shows a dorsal eminence, lying directly over the marked dorsal angle of the nucleus alæ cinereæ. No attempt has been made to model or correlate in any way the loose vascular tissue in the area postrema of Retzius. The cephalic limit of the nucleus alæ cinereæ, when related to the anatomy of the floor of the fourth ventricle, lies ventral to the nucleus nervi vestibularis medialis at a level with the middle of the nucleus funiculi teretis. This corresponds to Streeter's cephalic limit.

Streeter gives the area acustica as that part of the ventricular floor which lies lateral to the anterior fovea and the fovea vagi and the lateral furrow connecting the two. This large area is divided into the median vestibular field and a lateral cochlear region. As seen from inspection of figure 3, these two regions are, in this adult brain-stem, occupied by the two nuclei—that of the vestibular nerve and that of the cochlear nerve. Streeter places the vestibular nucleus in his diagram of the ventricular floor as lying entirely lateral to the lateral furrow. The median nucleus of the vestibular nerve in the reconstruction extends mesially to the lateral furrow in the region just caudal to the sixth nucleus, in which situation it seems on cross-section to occupy most of the region just beneath the ventricle. In general, the vestibular nucleus follows the gentle convexity of the lateral furrow, but in the region just caudal to the nucleus nervi abducentis it shows a rather marked angular convexity and concavity. Streeter does not give the cephalic

limit of the nucleus, but as seen from dorsal view it extends to approximately the same level with the superior end of the nucleus of the sixth nerve.

In the cephalic portion of the fourth ventricle, just superior to the area of the striæ medullares, and lying somewhat lateral to the median line, is the eminentia abducentis (Streeter) formed by the nucleus nervi abducentis and the genu of the nervus facialis. As shown by a comparison of the corresponding areas of the two sides of the reconstruction, the eminence is directly dorsal to the inferior part of the nucleus of the sixth nerve (figure 4). The genu of the seventh nerve is not shown in the model, as only nuclear material was considered. This eminentia abducentis is continued cephalad in a long cephalo-caudal elevation toward the aqueduct of Sylvius. By comparison, this elevation running to the cephalic limit of the model is seen to be overlying the indefinite nucleus incertus in its whole course. Beneath this nucleus, in the cephalic portion, is the nucleus reticularis tegmenti pontis, shown in figure 4, the mesial view. The fovea mediana, having no correspondence to any underlying nuclear structures, is shown between the nucleus incertus on the left and the eminence of the nucleus incertus on the right. Streeter speaks of the overlapping of the sixth nucleus by the nucleus incertus, but does not picture their relationship in his diagram of the floor; a comparison of the findings therefore can not be made, but it is more than likely that the limits are approximately identical.

The motor portion of the nucleus nervi trigemini lies slightly caudal and mesial to the cephalic ending of the vestibular nuclear complex in the anterior fovea (fovea trigemini). This coincides with Streeter's diagram of the terminations of the two nuclei. The overlapping of the nucleus incertus by that part of the fifth nucleus which lies in close relation to the brachia conjunctiva is shown in Streeter's diagram and in the dorsal view of this reconstruction.

NUCLEUS NERVI HYPOGLOSSI.

Arising in the central gray matter, on a level with the caudal pole of the nucleus olivaris inferior (figure 10), 5.6 millimeters cephalad to the superior limit of the decussatio pyramidum, the nucleus of the hypoglossal nerve extends dorsally and cephalad to terminate about the middle of the nucleus intercalatus. It measures in this adult medulla 11 millimeters in length and averages in transverse diameter about 1.7 millimeters. The measurements given by Streeter for the nucleus are 12.3×2.2 millimeters.

The nucleus lies in its caudal portion ventral to the central canal of the spinal cord, close to the mid-line. Its mesial surface maintains throughout intimate relation to the mid-line of the medulla, and the whole nucleus constantly lies ventral to the central canal and the widened fourth ventricle (figure 4). In its lower three-fourths, this hypoglossal nucleus is covered dorsally, and on the dorso-lateral surface by the nucleus alæ cinereæ (figure 10); in the cephalic one-third, it is capped dorsally and laterally by the

nucleus intercalatus. Lateral to the nucleus, throughout its extent, the nucleus of the tractus solitarius occurs. Ventral to it, are the formatio reticularis and the fasciculus longitudinalis dorsalis, with also the nucleus of Roller in its cephalic one-third (figures 4 and 11).

Miss Sabin did not model the hypoglossal nucleus accurately, because of technical difficulties, but merely represented its position in her reconstruction. She states that the nucleus corresponds in length, however, to the nucleus olivaris inferior. In this reconstruction of the adult medulla, it is seen that the nucleus of the hypoglossal nerve corresponds merely to the caudal three-fifths of the inferior olive. The hypoglossal and intercalated nuclei, on the other hand, together correspond to the cephalo-caudal extent of the inferior olivary nucleus.

The nucleus nervi hypoglossi may be described as an elongated column of cells, pentagonal in cross-section, gradually increasing in size from its caudal extremity to its dorsal angle at the eminentia hypoglossi and then rapidly tapering to its cephalic pole (figure 4). It presents for examination (in addition to its caudal and cephalic poles) five surfaces—mesial, lateral, ventral, dorso-mesial, and dorso-lateral. The characteristics of the nuclear form are shown in large part in figure 4, a mesial view. The dorsal border shows a marked dorsal angle at the junction of the cephalic one-fourth with the caudal three-fourths. Above this, the border curves ventrally to terminate just anteriorly to the nucleus intercalatus, in a rather sharp pole. Caudally from this angle, the dorsal border slopes in a fairly straight line caudally and ventrally; this border shows several depressions with curving limits. In the caudal part the dorsal border dips into a rather deep ventral depression, then projects directly caudally for a short distance, to turn sharply ventrally, forming the inferior pole. The ventral border, from mesial view, shows a gradual ventral bulging in its middle portion, sloping gradually into a shallow dorsal depression cephalad and into a more abrupt dorsal concavity caudally. In this cephalic depression lies the small nucleus of Roller. The mesial surface lying along the raphe is smooth, but the dorso-mesial surface, into which the mesial surface slopes, shows gradual irregularities due to the ventral depressions noted as occurring on the dorsal border. In the most caudal and cephalic portions the mesial and dorso-mesial surfaces are fused into one gradual convexity.

From dorsal view (figure 3), the dorso-mesial surface alone is seen. Arising as it does just caudally to the nucleus alæ cinereæ, this nucleus obscures the dorso-lateral surface in its lower three-fourths (figure 10) while the cephalic one-fourth of the nucleus of the twelfth nerve is covered by the nucleus intercalatus, which forms a well-defined dorso-lateral cap, closely adhering to the cephalic dorso-lateral surface. The elevation between the dorso-mesial and dorso-lateral faces of this hypoglossal nucleus is composed of two portions, both of which are fairly straight. The caudal three-fourths, that portion below the dorsal angle, slopes slightly away from the mid-line

as it ascends, while the cephalic one-fourth is turned toward the mid-line from the point of the dorsal angle.

On ventral view, the nucleus of the twelfth nerve shows a gradual increase in its transverse diameter in passing from its caudal to its cephalic pole. The widest portion of the nucleus is attained in the middle of the nucleus of Roller, cephalic to which the lateral wall of the nucleus rapidly curves mesially to its cephalic pole. In the region of the nucleus of Roller, the lateral ventral border is prolonged sharply ventrally for a short distance. The ventral surface of the nucleus is somewhat irregular and slightly curved in its lower two-thirds, with the convexity ventrally. It shows the single ventral bulging and the two dorsal depressions described as occurring in the ventro-mesial border.

The lateral surface of the twelfth nucleus in its caudal three-fourths is fairly smooth and regular, sloping (as it ascends) slightly laterally from the mid-line and also laterally in its dorsal portion. At the caudal end, the nucleus shows a slight lateral bulging. Above the dorsal angle of the nucleus, the lateral surface slopes in a convexity toward the mid-line to terminate in the cephalic pole. The lateral surface really loses its character as the nucleus intercalatus caps the twelfth nucleus, for the dorso-lateral surface here occupies the whole lateral extent of the cell-mass.

The dorso-lateral surface shows a more marked angle with the lateral surface than does the dorso-mesial with the mesial face. The dorso-lateral aspect of the nucleus is, in general, a flattened straight surface, larger and more striking than the dorso-mesial surface, with a broadened grooving in the caudal one-third, due to the projection of the lateral depression upon it. Slight ventral depressions occur on its surface, corresponding to those seen on the dorso-mesial face. The cephalic one-fourth of this dorso-lateral surface is in intimate contact with the lower end of the nucleus intercalatus. Beginning as a very narrow cap on the dorso-lateral surface of the hypoglossal nucleus, this nucleus intercalatus covers the remaining cephalic portion of the hypoglossal nucleus, gradually occupying its place as the dorso-lateral border is pushed toward the mid-line. This causes the superior one-fourth of the dorso-lateral surface of the hypoglossal nerve to look laterally, dorsally, and somewhat cephalad. This upper portion of the dorso-lateral face is much wider than the other portion of its surface as it assumes also the lateral aspect of the nucleus.

The caudal pole of the nucleus of the hypoglossal nerve shows as a flattened face, pentagonal in outline, which lies transversely across the medulla. This is due to the rather abrupt caudal beginning of the nucleus in its characteristic form. The cephalic pole is sharp, being formed by the approximation of the various surfaces of the nucleus.

Many descriptions of the nucleus nervi hypoglossi divide the nucleus into intra-ventricular and extra-ventricular portions. There is no morphological basis for such a division into two approximately equal parts and it

seems more sensible to consider the morphology of the nucleus in such a reconstruction than the arbitrary division adopted by other authors without reference to its actual morphology. The relation of this nucleus to the area hypoglossi in the floor of the fourth ventricle has been considered under that subdivision of this paper.

NUCLEUS ALÆ CINEREÆ.

The caudal extremity of the nucleus alæ cinereæ is situated just cephalad to the caudal limit of the nucleus nervi hypoglossi (figures 3 and 4, *ac*), at a point slightly more than 5.6 millimeters above the cephalic limit of the decussatio pyramidum. From this caudal pole, the nucleus extends dorsally and cephalad, to become superficial under the floor of the fourth ventricle; then continues ventrally and cephalad, with slight lateral deflection, to terminate ventrally to the nucleus vestibularis medialis, just cephalad to the superior termination of the nucleus tractus solitarii, about on a level with the middle of the nucleus intercalatus (figure 4). The extreme cephalo-caudal diameter measures 11.7 millimeters and its greatest transverse measurement is 2.0 millimeters. Streeter gives 13.5×2 millimeters as the dimensions of the nucleus in his study.

The nucleus alæ cinereæ presents varying relations in the several portions of its extent. Throughout the caudal three-fourths of the nucleus of the hypoglossal nerve, the nucleus alæ cinereæ lies dorsal and lateral to it, covering the dorso-lateral surface of the former (figures 3, 4, 10, and 11, *ac*). The nucleus intercalatus, in the cephalic half of the nucleus under consideration, lies ventral and mesial to it until the nucleus alæ cinereæ dips ventrally when it assumes a mesial and finally a dorso-mesial relation (figure 3). Lateral to the nucleus alæ cinereæ in its caudal portion is a small nuclear mass placed on the ventro-mesial convexity of the nucleus fasciculi gracilis, and also the nucleus fasciculi gracilis and the nucleus vestibularis medialis (figure 10). In its most cephalic portion the nucleus tractus solitarii (Mellus) lies lateral (figure 11). In its caudal beginning, the nucleus alæ cinereæ is ventral to the nucleus fasciculi gracilis (figures 3, 4, and 10), but as the central canal of the cord widens out the nucleus vagi becomes superficial beneath the floor, to dip finally ventrally to the nucleus vestibularis medialis. Ventral to the nucleus alæ cinereæ is the nucleus nervi hypoglossi and the nucleus intercalatus. The formatio reticularis is in ventral relation in a small part of its course.

Mention has been made of a small nuclear mass lying lateral to the nucleus alæ cinereæ, between it and the ventro-mesial surface of the nucleus fasciculi gracilis. This mass of nerve-cells and neuroglia-cells forms a thin sheet which follows the convexity of the ventro-mesial wall of the gracile nucleus. Its dorsal border is seen from dorsal view in figure 3 and also on mesial inspection, in figure 4. In its longest cephalo-caudal diameter it measures 3.7 millimeters, while its dorso-ventral diameter (somewhat

oblique) averages 1.5 millimeters. Its other dimension is very small, as it is a sheet of three or four cells only in thickness. The nucleus begins below, at the same level approximately as does the nucleus alæ cinereæ. It then extends cephalad and dorsally, maintaining its close relationship to the convexity of the ventro-mesial surface of the nucleus fasciculi gracilis. Roughly, it forms a parallelogram with a smooth mesial surface which looks also ventrally. The cephalic border of the parallelogram is not straight, but is curved with a cephalic convexity. The superior cross diameter is also slightly greater than the corresponding measurement in its caudal portion. From the cephalo-ventral angle of the nucleus projects a well-defined spur which runs ventrally, cephalad, and somewhat laterally. In the middle of its cephalic half the nuclear material is divided into two portions by the central gray matter, but quickly reunites above, the resulting separation giving rise to fenestration of the model of the nucleus at this point. The nuclear mass is histologically very distinct. It is separated from the nucleus fasciculi gracilis by a thin sheath of nerve fibers, while from the nucleus alæ cinereæ it is segregated by both obliquely coursing fibers and by fibers running in a longitudinal direction. The nucleus stains much more deeply with carmine than does the nucleus alæ cinereæ. No large nerve-cells occur in the cell-mass, but many small cells are found, together with many neuroglia-cells. Few nerve fibrils occur in the nucleus.

A similarly differentiated nucleus, resembling this just described, is found in the central gray matter, somewhat caudally to the inferior pole of the nucleus nervi hypoglossi. Histologically and pyknotically, the two nuclear masses are similar. They bear approximately similar relationships to the central canal, both occurring lateral and dorsal to that structure. No connection between these nuclear masses, placed in the central gray matter, can be made out. On account of technical difficulties this lower cell-mass was not modeled, but, as far as can be stated from the results of study of serial sections, the lower mass also forms a somewhat similar sheet of cells, but possesses greater thickness than does the upper collection.

The significance of these two cell-sheets is not known. There apparently exists a very close relationship to the nucleus alæ cinereæ, especially in the more cephalic mass.

Jacobsohn (1909) has described, under the term "Nucleus sympathicus nervi vagi," a cell-collection which coincides in part with the more cephalic of the two nuclei under consideration and in part with the nucleus alæ cinereæ as here modeled. His upper limit to the nuclear material is placed at a much higher level than found in this model. Cajal has included similar cell-collections in the dorso-mesial nucleus of the tractus solitarius.

The nucleus alæ cinereæ may be roughly described as an irregularly shaped, curving nucleus, with dorsal convexity, which begins caudally as a thin sheet of cells widening out in its middle portion and exhibiting an irregular triangle on cross-section in its upper portion. Because of its marked

irregularities, the nucleus presents the following surfaces, more or less limited in extent: mesial, dorso-mesial, dorso-lateral, lateral, and a ventral border which widens into a ventral surface.

From mesial view (figure 4) the chief characteristics of the nucleus can be made out, as this view shows the dorsal convexity of the nucleus. Like the nucleus nervi hypoglossi, the nucleus alæ cinereæ shows a dorsal angle, occurring about the middle of its dorsal border. This underlies the eminence in the ala cinerea of the floor of the fourth ventricle and is quite marked, as shown in the drawing. Traced caudally from this point, the dorsal border runs ventrally, caudally, and mesially to reach a position close to the mid-line at the inferior extremity of the fourth ventricle. From this point caudally, the border runs caudally and ventrally, but not as markedly ventrally as just above. This change in direction of the dorsal border of the nucleus results in the formation of an oblique angle with the apex dorsally. Above the dorsal angle of the nucleus, the dorsal border is continued cephalad and slightly ventrally and laterally, this direction taking the nucleus ventrally to the dorsally projecting nucleus vestibularis medialis. This cephalic half of the dorsal border shows three gentle ventral depressions, the most cephalic being most marked and terminating in the cephalic dorsal bulging of the superior pole.

The dorso-mesial surface is that part of the nucleus which presents superficially beneath the floor of the fourth ventricle. It shows as a slightly convex face on mesial view (figure 4), which in general looks mesially and somewhat dorsally. It is marked off from the mesial surface by a change in the planes of the surfaces which causes a slight angle to be formed in the shape of a continuous line running from the ventricular limit of this face downward and ventrally in a gradual dorsal convexity. This forms the base of a triangle which the dorso-mesial surface composes. The line between the dorso-lateral and mesial surfaces at the inferior limit of the ventricular portion of the nucleus splits into two lines—a direct caudal line, short and marking the ventricular limit, and a prolonged, indefinite, ventrally curving line which goes to the caudal limit of the nucleus. Between the two lines is a small, smooth, irregularly triangular surface which looks directly mesially.

Between the dorsally convex line separating the dorso-mesial surfaces and the ventral border is the irregularly shaped mesial surface (figure 4). In its cephalic portion this surface looks almost exactly mesially, but a gradual rotation occurs, so that in the lower portions the surface looks obliquely ventro-mesially (figure 10). The upper extra-ventricular portion of the surface is narrow and somewhat triangular, the apex of the triangle being contained in the cephalic enlargement or knob. Below this narrow upper portion the nucleus forms a fairly accurate elongated rectangle, narrowing somewhat, however, in the caudal portion. The surface is marked by several rather superficial grooves and by one gradual but somewhat extensive dorso-lateral depression just caudal to the middle of the nucleus.

The dorsal border at its caudal extremity is continued at almost a right angle in the short, straight caudal border which extends in a ventral and lateral direction. This is rather abruptly rounded into the ventral border, which runs cephalad, with dorsal and lateral deviations. The ventral border is by no means straight. For a short distance after its caudal inception, it parallels the dorsal border, then loses most of the dorsal deflection as the nucleus widens. This change of direction results in a marked dorsal notch. Superior to this, the ventral border continues in a slightly irregular line to a point just above the level of the dorsal angle of the nucleus, where it shows a ventral bulging and thickening, due to the dorsal convexity of its border cephalic to this. This dorsal convexity of the ventral border, more marked at its ends than in its middle, is continued into a ventral projection of the nucleus just below the cephalic termination of the nucleus tractus solitarii. Above this ventral beak-like projection the ventral border curves abruptly dorsally into the superior pole of the nucleus. Just cephalic to the ventral bulging of the nucleus about its middle portion, the ventral border splits into a second line, which runs cephalad in a slight, dorsally convex margin. Between this margin and the real ventral border occurs a triangularly shaped ventral surface. The apex of this triangle lies in the ventral projection in the cephalic portion of the nucleus; the base is formed by the border between the mesial and ventral surfaces. This line of junction between these two surfaces continues upward, to end in a small ventral spur which lies mesial to and projects somewhat ventrally to the ventral cephalic border. This ventral surface shows a fairly smooth curving face, the convexity being dorsal and lateral.

The dorso-lateral surface of the nucleus alæ cinereæ is found only in the cephalic one-third of the nuclear mass (figure 3). It is a small irregular surface, just ventral to the dorsal border, narrower above than below, and possessing an irregular anterior border. This margin is composed of the ventral-lateral projections of the nucleus around the tractus solitarius, which is almost inclosed by two horns of this nucleus. This margin is irregular, but maintains a direct cephalo-caudal direction. Below, at the junction of the cephalic one-third and the caudal two-thirds of the nucleus, is a deep sulcus which separates it from the mesial surface. In the upper portion the dorso-lateral surface looks dorsally and somewhat laterally, but by a gradual rotation the surface in its caudal portion looks laterally and only somewhat dorsally.

The lateral surface of the nucleus is a very irregular but, in general, smooth area which is embraced between the ventral border, the lower two-thirds of the dorsal border, and the ventral margin of the dorso-lateral surface. Cephalad, it is a concave depression which surrounds the dorso-mesial aspect of the tractus solitarius. The horns of this embracing surface are the ventral margin of the dorso-lateral surface and the ventral border of the nucleus. The surface begins mesially and cephalad on the lateral

aspect of the mesially projecting, cephalic knob and then curves laterally and caudally. The surface shows a slight depression in its middle and a very large and rather deep depression just above and connecting with the sulcus which delimits the dorso-lateral surface. Below the sulcus the lateral surface is large and smooth, pentagonal in outline. The angles of the pentagon are formed by the junction of the sulcus with the dorsal margin, by the dorsal angle of the dorsal margin, by the ventral bulging of the ventral surface and the two caudal angles. In its cephalic portion, the lateral face looks laterally and somewhat ventrally, but in the caudal one-third of the nucleus the surface is directed almost wholly laterally. This change in direction of the surface is due to the narrowing of the dorsal, thickened portion of the nucleus, showing on the lateral face as a caudal and mesial sloping of the lower portion of the surface from the widened and thickened middle portion. The lateral surface shows a curving of its whole face with the convexity mesially. This curving is accounted for by the more lateral position of the upper portion of the nucleus in its cephalic two-thirds.

The greatest antero-posterior diameter of the nucleus occurs at the level of the dorsal angle and middle ventral bulging (figure 3). Both above and below this, the diameter is maintained with but gradual diminution. The nucleus exhibits its greatest transverse diameter, or is thickest, at the same level. Caudal to this, the nucleus rapidly becomes a thin sheet of cells, while in its superior portion it maintains a considerable transverse diameter.

NUCLEUS AMBIGUUS.

The adult nucleus ambiguus, as modeled on the left side of this reconstruction, consists of two main masses separated by a considerable intermission (figure 4). The lower cell-mass—oval with its longer axis parallel to that of the substantia gelatinosa—is found on the level of the middle of the true hypoglossal nucleus in a plane slightly cephalic to the caudal end of the dorsal accessory olivary nucleus. It is very small and the large motor cells can be identified only through a few sections in this region. The main column of cells in the nucleus ambiguus begins on a level with the middle of Roller's "small cell hypoglossal nucleus," caudal to the cephalic ends of the nucleus nervi hypoglossi, the nucleus alæ cinereæ, and the nucleus olivaris accessorius dorsalis. It is surrounded by the formatio reticularis, in which it lies; lateral to it is the substantia gelatinosa, and ventral are the dorsal accessory olive and the dorsal leaf of the main olive. Dorsally it is in relation to the nucleus tractus solitarii, the nucleus nervi hypoglossi, the nucleus alæ cinereæ, and in the upper part the nucleus intercalatus and the nucleus vestibularis medialis. Cephalad the nucleus extends to a level just below that of the caudal pole of the nucleus nervi facialis. The whole nucleus is shown in figure 4, a mesial view of the model. Between the level of the smaller nuclear mass and the upper nuclear column an occasional large motor

cell can be made out in the sections, but these cells have not been included, the model being only of those cells which show a characteristic grouping.

The superior cell-column in the nucleus ambiguus (figure 4) begins caudally as a very small column of cells, which rapidly widens into an oval cell-mass with the long, transverse diameter antero-posteriorly, but with the dorsal end slightly drawn toward the mesial line. Directly above this is a marked constriction, superior to which begins the main division of the cell-column. This is oval on cross-section, the long axis coinciding with the long diameter of the lower cell-mass. This main division progresses upward, widening somewhat at first, but soon gradually narrowing into a second constriction. Cephalic to this constriction is a small dilatation of the nuclear column, above which a third constriction occurs. The cells in the constriction increase in number and in distribution as one goes cephalad, the result being a slightly increased size of the column. This gradually narrows and tapers off into the cephalic termination of the column of cells. The cephalic ending concerns only a small column of cells, but is well defined.

NUCLEUS NERVI COCHLEÆ.

In the new-born medulla Dr. Sabin found that the nucleus of the cochlear nerve was rectangular in outline, with a thick ventral portion and a thin dorsal layer lying against the surface of the corpus restiforme.

The cochlear nucleus in the adult shows most of its characteristics on lateral view (figure 2). Lying lateral and, in part, ventral to the corpus restiforme, the nucleus contributes in part to the wall of the lateral recess of the fourth ventricle. Dorsal and mesial to the nucleus lies the corpus ponto-bulbare (Essick).

The lateral view (figure 2) of the cochlear nucleus reveals a large ventral parallelogram, from the spinal end of which the dorsal nucleus projects around the corpus restiforme. The ventral border is irregularly notched: the most cephalic of the notches corresponds to the entering root fibers. Below this notch the ventral border slopes caudalwards and dorsally—to turn abruptly, at the inferior limit of the nucleus, into a fairly straight dorso-ventral border. This straight caudal border, bending in the direction of the lateral limit of the corpus restiforme, curves cephalad to form the dorsal and mesial limit of the dorsal nucleus. The cephalic border is fairly straight in its dorsal half, with a general dorso-ventral direction, but with the ventral end slightly cephalad to the dorsal. About the middle of this cephalic border there occurs an abrupt turn cephalad, then a right-angled deflection ventrally, resumed in a general cephalic direction, parallel to the ventral border. The ventral broader and larger portion is further separated by a right-angled elevation of the dorsal portion continuing the dorso-ventral line from the middle of the cephalic border. This gives the appearance as if the ventral nucleus were inserted into the dorsal portion. With some histological proof and the peculiar morphologically suggestive separation, the segregation of

a ventral portion of the nucleus from the dorsal may be made, although it must be realized that the dorsal and ventral nuclei are undoubtedly the same continuous cochlear complex.

On dorsal view (figure 3) the nucleus shows the curving about the corpus restiforme and the very considerable transverse diameter of the nucleus. The groove suggesting the separation into ventral and dorsal nuclei is here readily seen. The ventral portion of the nucleus on this view shows as a triangular mass on cross-section, with the apex dorsal. This line of the apices lies in about the middle of the ventral mass and continues caudally below the point of origin of the fissure between the two parts of the nucleus. Over the lateral surface of the dorsal nucleus is a rather long and thin strip of nuclear matter similar to that of the nucleus.

On cephalic view, the most striking feature of the nucleus not shown on the other views is a marked hollowing of the superior surface of the ventral portion. The cephalic line, which shows on lateral view in this ventral portion of the nucleus, abruptly plunges medially into the smooth slope which forms the lateral nuclear wall of this fiber hollowing. The cephalic notch observed on the ventral surface is connected with this hollowing and the mesial wall is formed from the medial angle of the notch projecting dorsally and somewhat cephalad. On cephalic inspection also the transverse thickness of the nucleus can be made out. In the dorsal portion, the transverse diameter is about the same as the cephalo-caudal, but in the so-called ventral nucleus this transverse diameter is but two-thirds the cephalo-caudal diameter. The cephalo-caudal diameter of the ventral enlargement of the nucleus is thrice that of the dorsal projection.

Mesially the nucleus shows a fairly smooth curving outline, conforming to the lateral curve of the corpus restiforme.

NUCLEUS NERVI VESTIBULI.

In figure 3 is given the best idea of the general form of the nuclei of the vestibular nerve. The whole nuclear complex is shown more or less as a unit mass, extending from the cephalic limit of the nucleus fasciculi gracilis to the nucleus of the fifth nerve. In this cephalo-caudal diameter the nucleus of the vestibular nerve measures 14.7 millimeters. Its greatest transverse diameter, occurring on a level with the so-called ventral cochlear nucleus, measures 6.0 millimeters.

Study of the nuclei of the vestibular nerve has led to the conclusion that the individual cell-collections should really be considered only as parts of the main vestibular complex. Miss Sabin, in her reconstruction of the nuclei from the brain-stem of the new-born babe, divided the nuclear matter into two main masses—the cell-mass median to the vestibular tract (including the descending and ascending roots) and the cell-masses lateral and mesial to the tract and main cell-mass (the two composing the nucleus nervi vestibuli lateralis). The main cell-mass Miss Sabin then described under the

divisions of the mesial, superior, and spinal nuclei of the vestibular complex. Her reconstruction led to a much simpler and better idea of the vestibular complex than did her earlier contribution on the subject. In this reconstruction it was attempted to maintain, as far as possible, this more simple conception of the vestibular complex, as is undoubtedly justified on morphological if not on histological grounds. The nucleus nervi vestibuli lateralis has not in this study been separated from the median nucleus, as it was felt that any attempt to separate this group of motor cells could only result in the establishment of arbitrary lines of division. The separation of the nucleus nervi vestibularis spinalis (radix descendens) was, however, made, as this division is one upon which unanimity could be secured. The nucleus nervi vestibuli superior, comprising as it does the cephalic prolongation of the median nucleus, shows no caudal separation from the main nuclear mass. This coincides with Miss Sabin's reconstruction of the mass. As far as possible the description of the whole nuclear mass will be made from the standpoint of one cell-mass, but consideration will be taken of the divisions of the nucleus into its well-established four chief nuclei.

The dorsal surface of the vestibular complex lies beneath the floor of the fourth ventricle in the vestibular portion of the acustic triangle (figure 3). It is overlaid on its caudal portion by the gray matter and fibers comprising the ventricular lip of the corpus ponto-bulbare. Mesially the vestibular nucleus lies in relationship to the nucleus alæ cinereæ (figure 11), the nucleus intercalatus, the nucleus nervi abducentis, and the caudal portion of the nucleus incertus. On the dorso-lateral side of the superior half of the nucleus lies the brachium conjunctivum. Laterally we find the nucleus fasciculi cuneati, the corpus restiforme, and the brachium pontis, separating off the nucleus nervi cochleæ and the corpus ponto-bulbare. Ventrally there occur the long substantia gelatinosa, the nucleus tractus solitarii, and the formatio reticularis. These relationships are easily understood from inspection of figures 2, 3, and 4.

The main vestibular nuclear mass, when viewed from the dorsal surface (figure 3), as one passes from its caudal portion, exhibits a sudden widening in the region of the middle of the nucleus, corresponding to the lateral recess of the fourth ventricle. This relationship is well shown in Miss Sabin's reconstruction. Above this the main mass shows a sudden narrowing in the region of the lower end of the nucleus nervi abducentis and a second, just superior to this, where the fibers of the seventh nerve force the nuclear material from the median line. Above this more caudal constriction, the superior nucleus of the nerve may be said to lie, as it corresponds laterally to the level of entrance of the nerve root and the division into ascending and descending fibers. The most lateral projection of the whole nucleus represents the lateral collection of motor cells, comprising in part the nucleus nervi vestibuli lateralis. From the cephalic part of the median and from the superior nucleus, dorsal spurs and columns of cells lie in relationship to

the brachium conjunctivum. Lateral to the caudal portion of the median nucleus (figure 3) lies the radix descendens with its accompanying nuclear material, forming the nucleus nervi vestibuli spinalis. From lateral view (figure 2), the general triangular shape of the nucleus can be made out. The apex of this triangle projects laterally and ventrally to meet the incoming vestibular nerve. With this brief general conception of the whole nuclear complex we may proceed to a more careful description. The whole nuclear mass may be said to exhibit three surfaces for examination: dorsal, mesial, and lateral. The ventral surface is lost in the sloping of the ventral surface into the lateral. These surfaces will be described under the various nuclei comprising the complex.

NUCLEUS NERVI VESTIBULI MEDIALIS.

This portion of the nucleus extends from the cephalic limit of the gracile nucleus to the caudal border of the nucleus of the sixth nerve (figure 3). Laterally it is bounded by the nucleus nervi vestibuli spinalis in its caudal half and in its cephalic half by the corpus restiforme, except in the region of the nucleus nervi vestibuli lateralis. The nucleus may be divided, for description, into a narrow caudal half and a widened cephalic portion. On dorsal view (figure 3), the nucleus shows a fairly smooth surface which slopes ventrally toward the mid-line. Beginning below as a narrow strip of nuclear material with its long axis dorso-ventrally (figure 11), the nucleus widens but slowly in its caudal half. At the region of the opening of the lateral recess into the fourth ventricle, it abruptly projects laterally, almost attaining the mesial limit of the dorsal cochlear nucleus and covering dorsally the radix descendens. As the opening of the lateral recess closes cephalad the nuclear surface under the ventricular floor narrows (figure 12). When viewed dorsally (figure 3) the mesial border of the nucleus exhibits a cephalo-caudal direction with a deflection toward the mid-line as it ascends. In the region of the cephalic pole of the nucleus nervi hypoglossi (widest portion of the nucleus intercalatus) the mesial border of the median vestibular cell-mass shows a marked lateral notch. Above this is a slight transverse elevation across the nucleus as it widens out. At the lower limit of the sixth nucleus the mesial border curves rather sharply laterally and then turns cephalad again for a short distance. But from the point of occurrence of this lateral deflection this main vestibular cell-mass is considered as the superior nucleus. The lateral border of the median vestibular nucleus, after the short caudal portion which ascends almost parallel to the mesial border, runs cephalad and somewhat laterally. It is, in the main, a fairly straight border showing some irregularities, especially one gentle lateral projection just cephalic to the ventricular portion of the corpus ponto-bulbare. This lateral margin continues as a smooth, straight surface to the formatio reticularis in a direct dorso-ventral direction—the line of separation from the nucleus spinalis of the nerve. At the caudal limit of the lateral recess the

lateral border of the median nucleus curves directly laterally for some distance, then abruptly cephalad. This curving forms a lateral shoulder to the nucleus which approaches the dorsal cochlear cell-mass. Ascending, the lateral border again leaves the mid-line in a beak-like projection into the most lateral portion of the main cell-mass, the nucleus nervi vestibuli lateralis. Higher up the lateral margin continues straight cephalad, with a slight mesial slope, into the lateral border of the superior nucleus. Just mesial and somewhat cephalic to the projection constituting the lateral nucleus, the dorsal projection of the nucleus appears. This shows a prominent caudal margin which overhangs the main dorsal surface and curves into a sharp mesial border, receding above (figures 2 and 3). The dorsal projection is marked laterally by a slight ridge which terminates below in a marked dorsal spur. Between these borders is an irregular concavity (corresponding to the outline of the brachium conjunctivum) marked by two fenestrations (figure 3) in the nuclear material, through which large fiber bundles course. Just inferior to the caudal margin of the dorsal elevation is a marked space or hole separating the lateral nucleus from the mesial—a space resulting from failure to model the fiber bundles. Mesial to the depressed opening for this fiber bundle is a slight ridge on the mesial cell-mass.

The mesial surface of the nucleus nervi vestibuli medialis is well-defined and of a marked mesial convexity in the caudal half. In its wider cephalic portion the nuclear surface is poorly defined and is apparently a direct dorso-ventral surface, sharply limited from its dorsal and ventral aspect. The surface is widened considerably at a point on a level with the nucleus nervi vestibuli lateralis, but this widening is gradual and not abrupt.

The ventral surface is somewhat poorly marked in the caudal portion as the mesial curve is continued upon it. In the cephalic half it is fairly regular except for the elevation corresponding to the widening mentioned as occurring in the mesial surface. The ventral surface looks also mesially and in its superior portion passes directly into the lateral surface, being marked by depressions and irregularities along the line of its relationship to the substantia gelatinosa. In the caudal half the ventral surface terminates with its junction with the nucleus nervi vestibuli spinalis.

From lateral view (figure 2) the prominent features of the median vestibular nucleus are the dorsal projections of the cephalic part of the nucleus and the marked overhang (dorso-lateral projection) of the nucleus as it underlies the floor of the entrance to the lateral recess of the fourth ventricle. The gradual and complete fusion of the four nuclei in the complex is well shown in this view.

NUCLEUS NERVI VESTIBULI SPINALIS.

The radix descendens, with its accompaniment of nuclear material, has been modeled throughout its extent, even though in the more caudal portions the greater part of the tract was composed of fibers and not of gray matter.

It ends as a thin mass, lying with its long axis dorso-ventrally, lateral to the median vestibular nucleus (figure 3). Its caudal termination is just cephalic to the caudal ending of the nucleus just mentioned. In the first part of its course, the nucleus spinalis is covered dorsally by the nucleus fasciculi cuneati, but as one passes cephalad it soon presents dorsally, as a thin column just lateral to the caudal portion of the median nucleus (figure 3). Its mesial and lateral surfaces in this portion are fairly straight, the mesial well defined, but the lateral poorly differentiated from the nucleus fasciculi cuneati. It spreads out in its ventral portion, so that on cross-section the nucleus shows as a triangle (figures 11 and 12). As the lateral recess opens into the ventricle the median nucleus overlaps dorsally the spinal nucleus, which has gradually displaced laterally the nucleus fasciculi cuneati. Just cephalic to this overlapping, the nucleus spinalis becomes superficial beneath the corpus restiforme, occupying the region cephalic to the convex superior end of the nucleus fasciculi cuneati. On cross-section in this area the radix descendens of the nerve lies median to the former, being capped laterally by a dense sheet of nuclear material. Figure 2 shows the nucleus spinalis occupying the whole lateral field dorsal to the substantia gelatinosa. It shows in its lower portion a considerable depression, but soon widens laterally as the dorsal spurs appear on the median nucleus. The lateral border of this surface is at first coincident with the dorsal margin of the substantia gelatinosa, but (as the vestibular nerve enters) this lateral border of the spinal nucleus projects laterally and ventrally to form the apex of a large triangle comprising the whole lateral surface (figure 13). The nuclear material comprising the cell-sheath of the nucleus is composed of a caudal (more mesial) column and a cephalic (more lateral) column (figure 2). Between these the nerve enters the nucleus and separates it from the substantia gelatinosa. The upper cell-column slopes caudally, laterally, and ventrally from its origin in the superior nucleus; and so the spinal nucleus terminates in the somewhat irregular line of the accompanying cell-column as the vestibular nerve enters the brain-stem. These cell-columns about the nerve fuse in part at their ventro-lateral terminations with the cells of the corpus ponto-bulbare. Whether the cell-columns should be considered as vestibular or as part of the corpus is not wholly clear, but their histology and position argue strongly for inclusion in the spinal vestibular nucleus, as they hold analogous position to the cells in the radix descendens. Such, then, is the form of the nucleus nervi vestibuli spinalis—a small, thin leaf in its caudal portion, widening laterally to its base along the entering vestibular fibers.

NUCLEUS NERVI VESTIBULI LATERALIS.

With its clearly defined collection of large cells occupying the most lateral portion of the main vestibular cell-mass, the nucleus nervi vestibuli lateralis exhibits a more or less characteristic form. On the lateral side of

the main nuclear form the nucleus of Deiters shows a sharp caudo-lateral angle (figure 3) and a definite border ascending from this. Ventrally a sharp curve takes the cell-collection toward the mid-line. The lateral aspect (figure 2), shows this lateral wall curving sharply mesially and somewhat ventrally, to lose its character as the cells pass mesially through the lateral portion of the spinal nucleus. It is not a well-defined area at all and would not be differentiated on morphological grounds. It is merely a curving cap of cells over the lateral aspect of the medial vestibular nucleus. Tracing the cell-mass toward the mid-line, we find only scattered cells for a slight distance mesially, but these larger cells again become somewhat clumped as one approaches nearer the raphe. This increase in size of the cell-mass is represented in the form of the mesial vestibular nucleus by the eminence or smooth elevation on its ventral surface. As they approach the mesial surface of the medial nucleus, these motor cells become somewhat more scattered and the cell-mass curves dorsally to end in the medial nucleus. With such a morphology the nucleus lateralis of the vestibular nerve can not be regarded as more than a group of large cells lying upon the lateral and ventral surfaces of the medial vestibular nucleus and modifying in slight degree the external morphology of this chief nucleus. Miss Sabin in the new-born was able to make out a lateral and mesial cell-mass as constituting this nucleus of Deiters, but here in the adult the ventro-lateral portion is more developed with the mesial enlargement merely a scattering of the cells in the medial vestibular nucleus.

NUCLEUS NERVI VESTIBULI SUPERIOR.

Miss Sabin was unable to model completely the superior nucleus of the vestibular nerve, as some of it was destroyed when the cerebellum was cut from the brain-stem. In general she pictures the nucleus as being a tapering superior extremity of the median vestibular complex, with its medial surface parallel to the raphe. With this morphology this reconstruction of the adult nucleus coincides in the main. The nucleus represents the superior portion of the medial and also the spinal nucleus, with the dorsal projections more prominent than the mesial portion beneath the ventricular floor. Cephalad the nucleus ends at the caudal extremity of the main nucleus of the fifth nerve, as shown in figures 2, 3, and 4. The nucleus can best be described by consideration of the various surfaces of the other nuclei which pass into the superior nucleus.

When viewed dorsally (figure 3), the greater part of the superior nucleus appearing is that which lies just ventral to the brachium conjunctivum. The dorsal surface of this nucleus, underlying the floor, is quickly rendered very narrow by the two lateral deflections of the mesial border of the whole cell-mass—the inferior at the caudal limit of the nucleus nervi abducentis and the superior at the corresponding point of the nucleus incertus. This superior angle makes room for the outward coursing fibers of the seventh

nerve. From this point upward to the superior termination of the nucleus, the ventricular mesial surface is represented merely by a small mesial ridge, irregularly marked by projection and depression. This ridge occupies the lateral angle of the ventricular floor. Dorsal to this is the cell-mass which lies ventral to the brachium conjunctivum. Ventral to the ridge is a solid cell-mass which continues upward the oblique ventral surface of the medial nucleus. This surface runs cephalad, somewhat irregularly marked by smooth eminences, to end at the general level of cephalic termination of the nucleus. It lies ventral to the caudal spur of the motor cells comprising the main motor nucleus of the fifth nerve. This surface is fairly well separated from the substantia gelatinosa by a deep groove, crossed by many fiber bundles.

The lateral surface of this nucleus presents the shape of a triangle, with the base composed of the superior cell-column which accompanies the entering vestibular nerve. The medial side of the triangle is composed of the dorsal edge of the nucleus while the lateral side is the lateral limit of the nuclear material as it gradually recedes from the entering root. Figure 2 shows well this triangular shape, placed just cephalad to the ventral cochlear nucleus. The cell-column which projects caudally, laterally, and ventrally from this superior nucleus to the entering nerve is quite irregular in form, narrowing at its lateral extremity and widening as it approaches the nucleus. It lies in close relationship to the substantia gelatinosa as it nears the nucleus and forms a lateral wall which soon fuses with the ventral wall of the superior nucleus. As it approaches the cephalic limit, this lateral wall is continued laterally (at the ventral angle of the dorso-lateral face) into a long spur with a dorso-mesial projection (figures 2 and 3). Ventrally this spur is composed of a fairly large knob-like swelling. Cephalic to this spur a deep fissure runs almost directly transversely, separating the nucleus from that of the fifth nerve (figure 3). As one views this dorsally, the furrow is seen to become much less deep in its mesial extent and the separation at this point is made with considerable difficulty. This dorso-lateral surface of the superior nucleus represents the superior continuation of the vestibular nuclear material which underlies the brachium conjunctivum. On dorsal view (figure 3), this portion of the superior nucleus is characterized by a large dorsal projection at its caudal limit on a level with the caudal extremity of the sixth nucleus (figures 4 and 13). Above this smooth eminence, the surface plate enlarges mesially and laterally, with a rotation so that the surfaces face in a dorso-lateral direction. The superior portion of this surface is smooth, but the inferior and lateral parts are marked by irregularities in the shape of small elevations and depressions, with ridges and furrows also apparent. With the exception of a projection at the side of the marked dorsal eminence at the level of the sixth nucleus the mesial edge of this surface is straight, though it shows some slight irregularities.

On account of the thinness of this dorsal leaf, the mesial edge is fairly sharp as one passes upon its ventro-mesial surface. The leaf, however, rapidly increases in thickness as it goes toward the main cell-mass, reaching its greatest transverse width at the irregular ridge underlying the lateral angle of the ventricle.

NUCLEUS NERVI ABDUCENTIS.

With its inferior termination just caudal to the cephalic end of the nucleus intercalatus, the nucleus nervi abducentis extends almost to the cephalic limit of the nucleus vestibularis (figures 3 and 4). It measures in the long cephalo-caudal diameter 3.8 millimeters; in its dorso-ventral, 1.7 millimeters; and in the greatest transverse, 2.3 millimeters.

Mesial to the nucleus are the genu of the seventh nerve and the fasciculus longitudinalis medialis (figure 13). Dorsal to it in its middle is the loop of the seventh nerve, while above it is covered by the nucleus intercalatus (figures 3 and 13). The nucleus lies fairly superficial beneath the eminentia abducentis of the floor of the fourth ventricle. Lateral to the nucleus lie the nucleus vestibularis medialis and the emergent root of the seventh nerve. The abrupt notch made in the vestibular cell-mass to accommodate the nucleus is shown in figure 3. Ventral to the nucleus is the formatio reticularis. Just caudal to its inferior pole is found the nucleus vestibularis medialis, while slightly mesial to this is the cephalic pole of the nucleus intercalatus.

Miss Sabin describes and pictures the sixth nucleus in the new-born as an "almost round body." The general shape of the nucleus in the adult, as seen in figure 4, is that of an oval body with a depressed mesial edge and a bulging lateral border. The portion of the dorsal surface of the nucleus not obscured by the nucleus incertus is shown in figure 3. The most dorsally prominent portion of the nucleus is just superior to the caudal limit; it shows as a projecting ridge on the dorsal and mesial surfaces (figure 4). Cephalic to this margin, the mesial and dorsal surfaces are depressed, to give room for the looping fibers of the nervus facialis. The depression on the dorsal surface persists, as is shown by the gradual ventral slope of this section on mesial view. This slope forces the cephalic pole to a plane more ventral than that of the inferior pole (figure 4). While the mesial and dorsal surfaces show depressions, the lateral surface from dorsal view (figure 3) shows a marked lateral bulging which gradually rounds into the superior pole. Ventral to this lateral projection, seen from dorsal view, the nuclear material is hollowed out in a mesial depression on the lateral surface. The ventral surface, mesial to this depression, is well rounded into a mass which shows a marked inferior shoulder from which the surface slopes concavely into the cephalic pole. This may be seen in figure 4. This concavity necessarily pushes the superior pole dorsally, so that it lies dorsal to the mid-axis of the nucleus. The superior pole is a gradual convexity when

inspected from the ventral surface, while from mesial view it shows as a sharp angle due to the great ventral concavity and slight dorsal convexity causing it. The caudal pole is placed dorsally and laterally to the mid-axis of the nucleus. It is formed by the surfaces approximating in gentle convexities below the margin of dorsal and mesial projection. It is a rounded extremity, lying in close relation to the mesial vestibular nucleus. When viewed mesially (figure 4) the dorsal border of the nucleus forms a fairly straight line, somewhat notched by the lower extremity of the nucleus intercalatus. The ventral surface shows a marked convexity and bulging in its caudal portion, the cephalic portion remaining comparatively straight until the final concavity is begun.

All of the surfaces of the nucleus are, in general, rounded so that there are no margins between these faces. The irregularities and characteristics of the oval nuclear mass have already been pointed out and need no further description. The factors which seem to play the greatest part in modifying the true oval character of the nucleus are the superior portion of the nucleus intercalatus and the peculiar looping of the seventh nerve.

NUCLEUS NERVI FACIALIS.

The nucleus of the facial nerve, lying in the lateral depths of the formatio reticularis at about the level of the caudal end of the nuclei pontis, is shown in the mesial view of the model (figure 4). It also appears on cross-section in figure 13. The caudal end of the nucleus lies on a level with the most cephalic portion of the nucleus ambiguus. The cephalic pole of this nucleus corresponds in position to the similar pole of the nucleus nervi abducentis. In its cephalo-caudal diameter the nucleus measures 4.7 millimeters; in its greatest transverse diameter, 2.8 millimeters; and in its greatest dorso-ventral diameter, 4.1 millimeters.

The relations of the nucleus to other nuclear masses vary in the several portions of the nucleus. The substantia gelatinosa lies dorso-lateral to this nucleus nervi facialis (figure 13). Lateral and somewhat ventral to its caudal half is found the scattered nuclear material comprising the corpus ponto-bulbare. Ventro-mesial to its cephalic two-thirds lies the nucleus olivaris superior, in very close relationship throughout. The other relations of the nucleus are wholly concerned with the formatio reticularis.

Essick (1912) has described the nucleus of the facial nerve as being a pear-shaped cell-mass. With his description of the nucleus in the embryo, this reconstruction of the adult nucleus agrees. In general, the nucleus may be said to be a rounded mass which tapers gradually cephalad after a sudden constriction in its transverse and antero-posterior diameters (figure 4). Beginning caudally in a rather sharp pole, the nucleus increases very rapidly in all diameters, but especially in the dorso-mesial direction. This more rapid increase in the oblique diameter causes the nucleus to assume an approximately oval shape soon after its caudal origin. The surfaces are

well rounded and pass into one another insensibly as soon as the great increase in nuclear dimensions is attained. Slightly above the caudal pole a slight concavity is made out on its ventral surface, and this is merged cephalad with a slight ridge which sweeps from the middle of the ventral surface laterally and cephalad. This ridge is continued superiorly as a definite ventro-lateral projection of the nucleus, until it merges in the superior pole. Just inferior to this ridge in the caudal half of the nucleus is a deep depression on the lateral surface. Mesial to this ridge the nucleus is flattened into a ventro-mesial surface, along which course the cell-columns of the superior olive. Mesially, this surface insensibly blends with the mesial curving face. Two marked longitudinal fissures occur in the dorsal convexity of the nucleus. These begin slightly above the caudal pole and run as fairly deep furrows, becoming more superficial as they reach more cephalic regions (figure 4).

Just cephalic to the middle of the nucleus all of these rounded surfaces suddenly constrict to a considerable extent. From this point upward, the nucleus, much narrowed in the two horizontal diameters, gradually tapers to its sharp superior pole. This rounded caudal dilatation, with a constriction about the middle, passing into a tapering superior extremity gives the whole nucleus the appearance of a pear.

The description just given applies to the nucleus on the left side of this adult medulla. Although the nucleus on the right of this brain-stem was not modeled, it was studied with the view of comparing its superior termination with that on the left. The cell-mass on the left side, as modeled, shows quite rapid tapering of the cephalic pole of the nucleus as compared with the right. On the right, the characteristic motor cells and ground substance, comprising the nucleus nervi facialis, extend cephalad as a thin column to a much higher level than on the left. This would tend to make the right nucleus possess a much longer "neck" than the left and probably to be even more pear-shaped.

Attempts were made to separate the nuclear mass of the seventh nerve into the various component cell-masses, described as occurring in this nucleus by Van Gehuchten and Marinesco. While undoubtedly such divisions of the nucleus into component parts do exist in the human medulla, the modeling of these from the arbitrary outlines which were necessarily made to determine the cell grouping was impossible. However, the occurrence of the fissures and the ridge on the external surface of the nucleus is indicative of such a division of the nucleus.

NUCLEUS NERVI TRIGEMINI.

The nucleus of the nervus trigeminus has not been modeled in its entirety, as the model at its caudal end still possesses substantia gelatinosa (figure 8), while at its cephalic end the main nuclear complex is just developing (figure 14). This description, then, of the morphology of the nuclear

complex pertaining to the fifth nerve is necessarily incomplete, but it is included for the purpose of describing as much of the complex as exists in the model. The course and morphology of the substantia gelatinosa is practically complete in the extent of the model, and its description and relations should have value.

The substantia gelatinosa Rolandi is that long nuclear mass, extending from the upper cervical cord to the middle of the pons, which accompanies the pars descendens of the nervus trigeminus. It possesses a characteristic histology and is easily outlined in the medulla, but as it approaches the motor nucleus of the fifth nerve it is cut off by many fibers and is with difficulty delimited without the introduction of the individual element. The nucleus will be described as extending cephalad from the caudal portion of the model. Its relations to neighboring masses of gray matter will be considered. In general, the pars descendens of the fifth nerve lies directly lateral to it.

At the caudal extremity of the model, the substantia gelatinosa caps the posterior column of the gray matter of this upper cervical cord. It is a convoluted mass and fills the greater part of the column (figures 8 and 9). In modeling, it was necessary to consider it as completely filling the column—a thing which it does very soon as one goes cephalad (figure 10). At the caudal extremity of the model, then, the substantia gelatinosa practically forms the oval posterior column which lies dorso-lateral to the central canal. It possesses a smooth contour, as shown in figures 1, 2, and 3. The long axis of the oval lies in an oblique plane, the lateral portion being dorsal to the mesial extremity. The column extends slightly cephalad to the superior termination of the decussatio pyramidum in a straight cephalo-caudal direction (figure 2). It widens from below upwards in this portion, as shown in the same figure, a widening to be accounted for both by the increased size of the substantia and by the rotation of the long axis of the oval in a dorso-ventral direction. This is shown in figure 9, where the long axis of the larger oval has its dorsal extremity somewhat mesial to the ventral. On the dorsal surface there occurs a slight eminence just above the caudal ending of the nucleus fasciculi gracilis, as shown in figure 3. The ventral surface is marked by a somewhat larger eminence in the middle of the decussatio pyramidum (figure 1). As shown in figure 3, the mesial border extends cephalad and only very slightly laterally until the region of the inferior end of the nucleus fasciculi cuneati is reached. It then is pushed laterally quite markedly and is overlaid by the projections of the nucleus of Blumenau. The lateral margin of the substantia shows on dorsal view a gradual lateral deflection.

Figure 2, the lateral view, shows the widened dilatation of the nucleus just cephalic to the superior extremity of the decussation of the pyramids. Superior to this, the substantia diminishes slightly in size and shows a gradually increasing dorsal curving for a considerable distance. Its lateral

surface is overlaid by the lateral plate of the nucleus of Blumenau already described (figure 10). As this lateral plate recedes from its surface, the substantia is characterized by a smooth notch on its ventral surface, followed by a ventral projection toward the middle of the nucleus lateralis, and slightly superior to these by a sharp dorsal spur. Figure 2 gives these markings. The mesial surface throughout this extent is quite smooth and rounded. The long axis of the oval still continues in the dorso-ventral direction. This portion of the substantia, lying caudal to the cephalic pole of the nucleus lateralis, shows but a slight lateral deflection. Just at the level of the cephalic pole of the nucleus lateralis and mesial to the main portion of the nucleus ambiguus, the substantia gelatinosa becomes quite thin, with the maintenance of the dorso-ventral direction of the long axis (figure 11). It takes a slight, rather abrupt, mesial bend at this point, to be succeeded quickly by a lateral deflection. These changes in direction of the main axis of the nucleus can be made out in figure 4. From this point, cephalad to its termination in the main sensory dilatation of the nucleus, the substantia continues the dorso-lateral deviation of its cephalic course by a series of slight mesial and lateral deflections similar to those just described.

Around the cephalic end of the nucleus tractus solitarii, the mesial surface of the substantia gelatinosa projects dorsally and somewhat mesially, to join with the ventral surface of the nucleus nervi vestibuli medialis (figures 4 and 12). Just superior to this dorsal projection there occurs a circumscribed deep depression, which is bounded ventrally by a rounded edge. The substantia just cephalic to this is raised in a gradual but marked mesial eminence. The oval of the substantia continues upward, bending somewhat laterally as it passes the nucleus nervi facialis. In this region the long axis of the oval becomes more oblique as its ventral edge is moved laterally. Its dorsal margin joins with the nucleus nervi vestibuli superior by large bridges of tissue (figure 13), which intermit in places. In the region of the superior portion of the nucleus of the seventh nerve the substantia gelatinosa becomes very irregular; it decreases in size and is broken by many fiber bundles as they course through it in all directions. Continuing ventrally to the cephalic end of the nucleus nervi vestibuli superior, it merges with a lateral sheet of cells which lies ventral to the most ventro-lateral portion of the superior vestibular nucleus. The fusion of the substantia gelatinosa with this lateral nucleus of the complex takes place at the level of the superior pole of the seventh nucleus, slightly cephalad to the caudal origin of the lateral sheet of cells. From this point cephalad to the termination of the model, the nucleus may be described as a lateral portion and the median motor portion, the nucleus motorius princeps nervi trigemini.

When viewed from the lateral surface the nucleus of the fifth nerve shows as an irregular mass placed between the ventral border of the superior vestibular cell-mass and the dorsal border of the lateral wall of the pontine

nuclei. Its ventral border (figure 2), overlying laterally the dorsal terminations of the pontine wall, shows a curving with the convexity dorsal. The superior border winds about the cephalic ventral angle of the superior vestibular nucleus and then projects mesially along the straight ending of the latter nucleus on the dorso-lateral plate. From the cephalic ventral angle of the superior vestibular nucleus, to the termination of the model, the lateral wall of the fifth nucleus is marked by an irregular lateral projection. This is due to the sudden widening out of the sensory reception nucleus which caps the superior end of the substantia gelatinosa. The expansion shows laterally (figure 2) as a corrugated and notched projection cephalic to the dorsal spur at the superior end of the vestibular nucleus, and extends cephalad to the limit of the model. It is placed at first at some distance laterally from the brachium conjunctivum, but it approaches the ventral lateral margin of this very soon and sends a short dorsal spur around its lateral and dorsal margin. This is shown at the extreme limit of the model (figures 2 and 3). The lateral surface passes insensibly into the smooth and extensive dorso-lateral plate of the nucleus, except at the cephalic limit of the cell-mass, where the surface passes over the dorsal spur. The dorsal-lateral plate (figure 3), underlying ventrally the brachium conjunctivum, is practically smooth throughout. Its mesial border is somewhat irregular, but it shows caudally a rather rapid mesial curvature, which becomes very mild in the cephalic portion of the model.

The ventral surface of the dorso-lateral plate is fairly smooth, and the plate is much thicker transversely just cephalic to the upper limit of the superior vestibular nucleus. This thickness reaches its maximum in the lateral angle of the ventricle, where it exists as a marked rectangular ridge. As one passes forward, the dorsal and ventral surfaces of this ridge approximate and the ridge merges into the thickened triangular plate. This thickened triangular plate has its base in the caudal, thickened portion of the dorso-lateral plate and extends cephalad, with its dorsal edge overlying mesially the ventral surface of the dorso-lateral plate, to terminate by ventral deflection in the column of the nucleus motorius princeps nervi trigemini. The rectangular column is composed of large polygonal cells closely grouped together in its caudal extremity, but as it loses its character cephalad these cells disappear from it.

From mesial view (figure 4) the chief motor nucleus of the fifth nerve is seen to begin as a marked caudal spur which lies mesial to the cephalic portion of the superior vestibular nucleus. This spur is composed of fairly large cells. Traced cephalad the spur expands in the transverse diameter, but especially in the dorso-ventral direction. This expansion occupies the whole mesial surface of the nucleus as the superior vestibular nucleus terminates. It shows a wide, gentle, mesial prominence as the nucleus meets with the lateral wall of the nuclei pontis, ventral to which prominence the wall slopes laterally and ventrally. This prominence gradually subsides as

it goes cephalad and this portion of the nucleus becomes a thin sheet of cells, overlying the fiber bundle which separates it from the dorso-lateral plate. The surface is irregular, from the occurrence of small prominences upon it. On its most cephalic portion in this model it shows several ventral projections which overlie mesially the lateral pontine wall (figure 14). Between the mesial eminence on this side and the rectangular column of large cells (mesencephalic root) is a marked ridge lying just ventral to the ventro-lateral angle of the fourth ventricle. It begins caudally as a small column of cells in the indifferent gray matter at the angle of the ventricle and continues cephalad to the limit of the model (figure 14). Its cephalic course, in the extent of the model, is somewhat dorsal and mesial. The mass expands as it goes cephalad into a mesial elevated ridge which becomes greater in the mesial and dorsal projections. Soon after it arises caudally, it is well marked off from the mesial cell-mass of the nucleus, but its dorsal limit is not well defined until after the triangular plate, ventral to the dorso-lateral roof plate, has joined with it. Histologically the mass is well differentiated.

NUCLEUS INTERCALATUS.

With its caudal extremity at the dorsal angle of the nucleus nervi hypoglossi and with its cephalic termination just cephalic to the inferior limit of the nucleus nervi abducentis, the nucleus intercalatus of Staderini and Von Gehuchten extends superficially beneath the floor of the ventricle, underlying the area plumiformis (figure 3). The nucleus measures in its cephalo-caudal axis 8.3 millimeters and its greatest transverse diameter measures 2.3 millimeters. Corresponding measurements given by Streeter are 11 millimeters and 2.0 millimeters. Hence, in the medulla sectioned by Streeter the nucleus was longer and perhaps narrower than in the medulla used for this reconstruction.

Dorsally, the nucleus intercalatus is covered solely by superficial neuroglia and by the ependyma of the ventricle, except in its cephalic portion where the striæ medullares course across it. The caudal two-fifths of the nucleus lie mesially in relation to the dorso-lateral surface of the nucleus nervi hypoglossi and laterally to the nucleus alæ cinereæ. The mesial relations of the cephalic three-fifths of the nucleus are with the nucleus funiculi teretis and with the raphe; the lateral relations of this portion of the nucleus are with the nucleus nervi vestibularis medialis and with the nucleus nervi abducentis in the most superior part. Ventrally, the nucleus is covered by the formatio reticularis. Such, then, are the relations of the nucleus intercalatus to the adjoining masses of nuclear material.

The dorsal view of the nucleus intercalatus (figure 3) and the mesial view (figure 4) show the general morphology to be that of a diamond, or of two cones with their bases approximated. The point of maximum diameter occurs at about the junction of the caudal two-fifths with the cephalic

three-fifths. Above this the nucleus tapers gradually to its cephalic pole; while in the lower two-fifths the nucleus narrows to a very thin edge. The caudal two-fifths of the nucleus present four surfaces for examination—dorsal, ventral, mesial, and lateral—but the cephalic portion of the nucleus is more or less rounded on transverse section, so that no distinct surfaces are made out.

From observation of serial sections of the brain-stem, inspected in order from the spinal cord upward, the nucleus intercalatus is first noticed caudally as a thin cap over the dorso-lateral surface of the nucleus nervi hypoglossi. This cap of cells gradually broadens, taking the place of the decreasing hypoglossal nucleus mesially and widening somewhat laterally, to reach its greatest transverse and dorso-ventral diameters at the level of the cephalic termination of the nucleus of the twelfth nerve (figures 3 and 4). The mesial surface of this caudal two-fifths of the nucleus, hence, faces mesially and somewhat ventrally as it conforms to the dorso-lateral face of the hypoglossal nucleus. The surface is a smooth plane, narrowing in its upper portion, although still showing dorsally to the motor nucleus but terminating very quickly to pass into the cone-like upper three-fifths. The wide caudal beginning of the nucleus intercalatus gives to this mesial caudal surface a triangular aspect.

The dorsal view (figure 3) of the nucleus in its caudal two-fifths shows also this triangular appearance with the apex downward. The mesial dorsal angle of the nucleus is about 110°, sharply defined and fairly straight. The lateral dorsal edge, however, shows considerable curving, with the convexity lateralwards, as the nucleus widens with the ventral dipping of the nucleus alæ cinereæ. This convexity gradually slopes into the upper core of the nucleus. The dorsal surface of the lower two-fifths of the nucleus is fairly smooth, with a gentle dorsal convexity. Two poorly defined and shallow ventral depressions occur on its surface.

Ventrally, the surface of the nucleus intercalatus is also smooth, with a slight ventral convexity. The mesial ventral border of this nucleus exhibits a marked lateral convexity in its lower portion, followed above by a mesial curvature. The lateral ventral border is fairly straight and runs almost exactly in the cephalo-caudal axis.

A rectangle is formed by the lateral surface of the nucleus. This face is not so smooth as are the other three surfaces in the caudal two-fifths of the nucleus; two mesial concavities mark this surface, between which occurs a fairly prominent ridge.

The arbitrary division for description of the nucleus intercalatus is marked by a slight transverse ridge on the dorsal and mesial surfaces, and by an elevation at the cephalic end of the ventro-lateral angle. Above this the nucleus forms a gradually tapering truncated cone, as seen in figures 3 and 12. The mesial surface shows a marked lateral bowing to accommodate for the nucleus funiculi teretis (figure 12); the border turns

abruptly laterally at the caudal end of the nucleus of the round bundle and then gradually cephalad to the cephalic pole of the nucleus intercalatus. The borders of the upper three-fifths of the nucleus intercalatus are fairly straight and gradually converge, to form an abrupt cephalic pole, mesial and slightly cephalic to the caudal extremity of the nucleus nervi abducentis (figure 3).

The relative dorso-ventral and transverse diameters of the upper cone of the nucleus and of the region of greatest thickness may be made out by comparison of the dorsal and mesial views (figures 3 and 4). The two diameters in these portions of the nucleus intercalatus are approximately equal. Below the area of greatest dimensions, the dorso-ventral diameter remains practically constant, while the transverse diameter diminishes rapidly as one passes caudally.

NUCLEUS TRACTUS SOLITARII.

In this reconstruction of the adult medulla, the nucleus lying lateral to the fibers of the tractus solitarius was modeled. Mellus (1903) described this nucleus in the medulla of the dog and identified a similar chain of cells lying lateral to the tractus in the human medulla. It was considered that this cell-column probably more truly represented the nucleus of the solitary bundle than do the irregular and ill-defined cell-groups situated mesially to the tractus, between it and the nucleus alæ cinereæ. The dorso-mesial cell-mass has been included by several authors as an integral part of the nucleus of the solitary bundle; one portion of this dorso-mesial cell-collection has been described in the subdivision of this study dealing with the nucleus alæ cinereæ.

The caudal end of this continuous chain of cells lateral to the tractus solitarius lies at a slightly higher level than does the caudal end of the nucleus alæ cinereæ (figure 10). The nucleus ends above just caudal to the superior termination of the nucleus alæ cinereæ (figure 4). Its cephalo-caudal length is 10.1 millimeters, just slightly less than that of the nucleus alæ cinereæ. Along the mesial and dorso-mesial border of the nucleus runs the tractus solitarius. Dorsal to the nucleus is the nucleus fasciculi gracilis in the caudal half, while in the cephalic half the nucleus nervi vestibuli pars descendens occupies this position (figure 11). Lateral to the nucleus is the nucleus fasciculi cuneati and in the most cephalic portion the substantia gelatinosa. Dorsal to the nucleus lies the nucleus alæ cinereæ, while mesial to it lies the nucleus nervi hypoglossi. Ventrally and laterally from the nucleus of the tract is found the substantia gelatinosa. At no point is the nucleus at all superficially placed as regards the floor of the ventricle.

The nucleus begins below as an irregular column of cells, and runs from this point cephalad, somewhat ventrally and laterally. The caudal three-fifths of the nucleus form an irregular cell-column, almost round on cross-section and situated at some distance mesially to the curving ventro-mesial

aspect of the nuclei fasciculorum gracilis et cuneati. In the upper two-fifths of the nucleus the cell-column becomes flattened, so that the long axis lies in the dorso-ventral plane. About the middle of the nucleus there occurs a well-marked, narrow, ventral spur; just cephalic to this are two smaller and less well-marked dorso-mesial spurs. At the level of the more cephalic of these spurs a marked dorsal concavity occurs on the ventral border, compensated by a corresponding dorsal convexity. Cephalic to the curving resulting from that concavity and convexity, the nucleus resumes its straight course. From mesial view the cephalic half of the nucleus appears much larger than the caudal portion. This appearance is due only in part to the flattening above recorded, but there is an actual increase in the cross-section of the nuclear material. The mesial surface of this cephalic half of the nucleus is rendered irregular and rough by slight depressions and ridges. Just before its cephalic termination, at a point where the nucleus vestibularis medialis and the substantia gelatinosa come into contact, the nucleus of the tractus solitarius exhibits an abrupt dorsal shoulder which rounds out into the cephalic pole. This dorsal beak-like projection lies just lateral and cephalic to a ventral projection from the nucleus alæ cinereæ. The lateral surface of the upper two-fifths of the nucleus conforms to the curve of the mesial surface of the nucleus of the fasciculus cuneatus.

NUCLEUS OF ROLLER.

The nucleus, described by Roller (1881) as a "small-cell hypoglossal nucleus," has been modeled in this reconstruction. It lies in the superior dorsal depression on the ventral surface of the nucleus nervi hypoglossi (figure 4). In its long cephalo-caudal diameter it measures 3.3 millimeters and has an average transverse diameter of 0.8 millimeter.

Roller described the nucleus as lying about in the middle extent of the hypoglossal nucleus. As seen from mesial view (figure 4), the nucleus lies ventral to the cephalic one-third of this nucleus of the twelfth nerve instead of in its middle region. It does lie, however, in the middle of the complex of nuclei nervi hypoglossi et intercalatus. The nucleus is composed of much smaller nerve-cells than those found in the hypoglossal and is separated from the nucleus by transversely coursing fibers (figure 11).

The nucleus may be described as a round column of cells presenting some slight surface irregularities. Its dorsal surface is curved to conform with the ventral surface of the hypoglossal nucleus, but on mesial view the ventral border shows an independent form (figure 4). Beginning caudally in the very sharp pole, the ventral border runs directly cephalad for a short distance and then turns in a sharp bend into a straight border running cephalad and dorsally to the upper pole, which is tapering and sharp. The nuclear mass widens and broadens quickly from its sharp caudal pole and continues as a rounded column for two-thirds of its length. Cephalic to this it tapers into its superior pole. The dorso-ventral and transverse

diameters are in the main equal, except in its middle portion, where the dorso-ventral diameter exceeds the other. This is coincident with a lateral depression on the mesial face—a depression pitted with small holes in the nuclear material.

From ventral and lateral inspection, the convex lateral border of the nucleus is made out. This margin shows a gentle curving throughout its extent, the convexity of the curve being directed laterally. The greatest lateral deflection of this border occurs at a level corresponding to the angle in the ventral border; cephalic to this deflection the curvature is very gentle.

NUCLEUS FUNICULI TERETIS.

Considerable variation in the extent of the nucleus funiculi teretis is found in different human medullæ. While the histological picture afforded by this nucleus is similar in all brain-stems, the differences in the cephalo-caudal dimensions and in the transverse diameter in several specimens are marked. Streeter, in his diagram of the relations of the underlying nuclei to the floor of the fourth ventricle, gives the nucleus funiculi teretis as extending from the superior pole of the hypoglossal nucleus to the superior pole of the nucleus intercalatus—in other words, occupying as a continuous column of cells the whole of the superior three-fifths of the nucleus intercalatus. In the adult medulla used for this reconstruction, two distinct and unconnected typical masses of cells are made out as comprising the nucleus funiculi teretis. The caudal mass of cells lies mesial to the cephalic portion of the nucleus nervi hypoglossi. It is a very small mass of cells, running through only a few sections, and is not included in this model because of technical difficulties. The larger cell-column has been reconstructed and shows in figures 3 and 4.

The nucleus lies superficially beneath its eminence on the floor of the fourth ventricle, just lateral to its mid-line. Laterally, it is in relation to the nucleus intercalatus; mesially, to the mid-line of the ventricle (figure 12). Ventrally, it shows an intimate relationship to the formatio reticularis.

As modeled, the nucleus appears as a short column of cells with rounded margins and a larger caudal portion which slopes into the smaller cephalic part. In cross-section, the nucleus shows as a triangle with convex surfaces and rounded edges (figure 12). When viewed dorsally (figure 3) it exhibits almost a constant transverse diameter throughout its extent with a fairly straight and flat lateral surface and a rounded dorsal face which curves rapidly into the mesial surface, as is seen on cross-section. On mesial view (figure 4), the cephalo-caudal dorsal border is markedly contrasted with the sloping, somewhat irregular ventral line of the nucleus. The caudal border, on mesial view, is wide and turns abruptly into the ventral margin, which slopes irregularly to the tapering upper pole. This ventral margin shows a slight dorsal notch, cephalic to which the borders run less markedly dorsally.

This gives rise to the broadened caudal half of the nucleus and a smaller tapering superior portion. The upper pole is rounded and small. The surfaces of the nucleus are all fairly smooth and regularly sloping into each other. The ventral surface shows an irregularity coincident with the dorsal angle in the ventral margin. It is flatter and less rounded than the mesial and dorsal surfaces.

NUCLEUS LATERALIS.

Inserted in the formatio reticularis of the medulla between the substantia gelatinosa of the nervus trigeminus and the inferior olivary nucleus is the column of cells known as the nucleus lateralis (figure 11). Beginning caudally at the level of the third dorsal transverse sulcus of the olive (a point midway between the inferior end of the dorsal accessory olive and the caudal pole of the inferior olivary body), this lateral nucleus extends cephalad to the superior limit of the dorsal accessory olive. Dorsal to the nucleus is the substantia gelatinosa; ventral to it is the dorsal leaf of the olive. Its mesial edge is parallel in part to the lateral border of the dorsal olive. Laterally the nucleus is in relation to the corpus restiforme.

These, then, are the relations of this nucleus lateralis to the other nuclear masses about it in the medulla. The morphology of this nucleus, as reconstructed from the adult medulla, concerns a distinct and continuous column of cells, well differentiated from the formatio reticularis in whose lateral and ventral angle it lies (figures 2 and 4). At its caudal end the nucleus is small, but as it continues cephalad a gradual increase in size occurs, the nucleus reaching its maximum about the level of the middle of the dorsal accessory olive. Just below this level the nucleus sends out a distinct lateral spur which curves slightly ventrally to conform to the curvature of the olive. While in the main the nucleus maintains a fairly straight course, it does show slight deflections from its main axis. One such deviation occurs just above its caudal end, the axis here turning ventrally after a short dorsal ascent. Five processes project angularly to the dorsal side from the main column of the nucleus, the most cephalic of these occurring just below the cephalic end of the cell-column, two occurring in the area of greatest cross-section, the other two being more caudally situated. Just caudal to the cephalic end is a prominent ventral spur, below which the nucleus widens after taking a slight curving direction, the convexity being dorsal. In the part of greatest cross area, the lateral surface is marked by deep notches. From the main cell-mass, several mesial projections occur; these have practically all a slight dorsal deflection. Two of these, in the caudal one-third of the nucleus, are especially well marked.

In the lower half of the nucleus the transverse and dorso-ventral diameters are about equal, but in the cephalic portion of this nuclear column the antero-posterior diameter is in excess of the transverse. The configurations of the nucleus are well shown in figure 2.

NUCLEUS INCERTUS.

Following Streeter, the indefinite nuclear mass, placed directly beneath the floor of the fourth ventricle in the prominence which runs toward the aqueduct of Sylvius from the eminentia abducentis, has been modeled as the nucleus incertus. It extends from its caudal limit at the middle of the nucleus nervi abducentis (figure 13) cephalad beyond the superior limits of this model (figure 14). Streeter diagrams it as beginning dorsally in the region of the knee of the facial nerve and extending cephalad with a lateral convexity.

Mesial to the nucleus is the raphe and mid-line of the pons; ventral to it occurs the formatio reticularis with also the nucleus reticularis tegmenti pontis (figure 4). Ventral to its most caudal extremity is the cephalic half of the nucleus nervi abducentis (figure 3). Lateral to the nucleus is the cephalic portion of the nucleus vestibularis and the nucleus nervi trigemini. Dorsal to the nucleus is the floor of the fourth ventricle.

In general, the nucleus may be said to be long and flat with a somewhat wider caudal extremity. Its limits are very poorly defined in cross-sections and it is felt that the terminations given this nucleus are subject to more individual variation than are those of any other nucleus modeled. The nucleus lies beneath the ventricular floor and constitutes in whole or in part the flattened nuclear material seen there. This gray matter is rich in a fine fibrillar network and in its midst there is differentiated, in part, the nuclear material as modeled. The nucleus may be said to present for examination only two surfaces, the dorsal and ventral, uniting with each other at the lateral and mesial borders.

As shown in figure 3, the nucleus begins abruptly in its caudal part but soon widens and presents a convex smooth surface dorsally. The mesial border is at first quite close to the mid-line of the ventricle, but after a short distance, in which a parallel relation is maintained, it curves laterally around the fovea mediana. After this lateral deflection, the mesial surface continues cephalad as an irregularly notched border which in general parallels the mid-line, although it gradually becomes more remote from it. This mesial curve corresponds in general outline to that given by Streeter in his diagram of the floor of the fourth ventricle. The lateral border of the nucleus is shown in part in figure 3. Beginning at the caudal extremity of the model, the border pursues at first a straight, oblique direction cephalad and laterally. Then it parallels the mid-line for a distance, forming the narrowed cephalic portion of the nucleus. As the nucleus narrows, this lateral margin curves toward the mid-line in a mesial convexity to form a notch in the narrowest part of the nucleus (figure 3). From this area cephalad, the nucleus widens somewhat and then narrows as it approaches the superior limit of the model. In accord with this, the lateral margin shows a gradual lateral convexity situated ventrally to the mesencephalic portion of the fifth nucleus.

The ventral surface of the nucleus is straight and smooth, except about the sixth nucleus. In this area the nucleus incertus exhibits a dorsal concavity with a ventral projection along the mesial surface of the nucleus nervi abducentis. This elevation vanishes as the cephalic portion of the sixth nucleus is reached, and cephalic to this the nucleus maintains its smooth and flat form.

The relative diameters of the transverse and dorso-ventral portions of the nucleus can be made out by comparison of figures 3 and 4. The dorso-ventral diameter, as is shown, is practically constant throughout the extent of the nucleus, while marked difference exists in the transverse.

NUCLEUS OLIVARIS INFERIOR.

From the caudal limit at a point in the basilar portion of the medulla 5.6 millimeters above the cephalic limit of the decussation of the pyramids, the nucleus olivaris inferior extends cephalad to the pons. The cephalo-caudal diameter of this nuclear mass measures 14 millimeters; the dorso-ventral, 4.3 millimeters; and the transverse, 6.7 millimeters. With the exception of the long cephalo-caudal diameter, the measurements given are those derived by taking the averages of a series of measurements. The transverse axis, if this term be used to designate the locus of the middle points of lines drawn from the dorsal to the ventral surfaces of the olivary leaves, varies in its relation to the antero-posterior plane of the raphe. In the lower one-third of the olive this transverse axis forms approximately a 90° angle with the raphe. This angle becomes increased in the more cephalic portions of the olive, being about 110° in its middle one-third and reaching in the most cephalic portions an angle of 135° approximately (figure 6). With this increase in the angle formed by the transverse axes of the olive with the raphe, the whole olive presents the appearance of having had its cephalic portion rotated laterally while the inferior or caudal end has been held in the transverse, right-angle position.

The volume of the olive, as determined by the displacement of water by its model with later computation from the volume displaced, is 0.14 cubic centimeter of nuclear material.

The general form of the inferior olivary nucleus is, as designated by Miss Sabin, that of a "hollow shell with a wrinkled wall." This is shown in the separate drawings of the olive (figures 5, 6, and 7) and in the lateral, ventral, and mesial views of the whole model (figures 1, 2, and 4). The nucleus presents for examination dorsal, lateral, ventral, mesial, cephalic, and caudal surfaces. The so-called dorsal surface is actually directed posteriorly only in the lower one-third of the nucleus, for it assumes a marked dorso-lateral deflection in its cephalic portion, with the increased angle which the transverse axis makes with the raphe in this superior portion. Unlike the olive in Miss Sabin's reconstruction, the dorsal surface does not pass

gradually into the lateral surface except in the cephalic portions, but it is rather sharply distinguished from the lateral surface. The dorsal surface is fairly straight, whereas the lateral surface shows a marked general convexity. On the ventral surface, the lower two-thirds are mainly flat, but the upper one-third exhibits a slope toward the dorsal surface. The mesial surface includes the hilum of the nuclear body and shows the invaginations of the convolutions of the dorsal surface.

The convolutions of the olive resemble, in general, those of the cerebral cortex as pointed out by Dr. Sabin. However, there is a very striking difference between the principal and secondary sulci here in the olive, a far more marked distinction than exists over the cerebral cortex. Generally, as in the new-born, the main furrows on the dorsal surface run transversely, but on the lateral surface this direction is converted into an oblique one, the sulci coursing somewhat laterally but chiefly ventrally and caudally (figure 2). The ventral surface shows the radial distribution of sulci as pointed out by Miss Sabin (figures 1 and 5).

Three principal sulci, corresponding to those in the medulla of the new-born, are distinguished on the dorsal surface of the inferior olive (figure 7). In the main, these are deeper and run more closely to the border of the hilum than do the other secondary furrows. These sulci divide the dorsal surface into four lobes—a cephalic lobe, occupying nearly one-third of the whole dorsal leaf; two middle lobes (the second and third lobes of Sabin), and the small caudal lobe. The first fissure, that between the cephalic and the second lobes, is the most poorly differentiated of the main sulci (figure 7, *a*). Its importance, however, is assured by its broad character and the general straight course which it follows, unaffected by the secondary sulci which enter it. This first fissure begins just lateral to the border of the hilum, courses out in a direct transverse line to almost the lateral limit of the dorsal surface, and then dips laterally, caudally, and ventrally as the main oblique fissure on the lateral surface of the olive (figures 5 and 7, *a*). The transverse dorsal portion of this main fissure is bisected by a very deep furrow, arising just cephalad to this first fissure—a fourth principal fissure. This deep furrow bisecting the transverse is continued caudally as the deepest fissure of this surface, forming the lateral margins of the second fissure and of the middle lobes. This deep fissure runs almost exactly cephalo-caudally with but slight lateral deviation in its caudal portion. Becoming more shallow about the middle of the third lobe, it curves over upon the lateral surface, to form the inferior limit of the middle lateral lobe. The second chief transverse fissure of the dorsal surface arises from the dorsal edge of the hilum at approximately its middle point and courses transversely to the deep cephalo-caudal fissure (figure 7, *b*). Its direction is transverse for three-fifths of its length and then becomes caudally inclined, to fuse with the cephalo-caudal fissure at an angle of 45°. This second principal sulcus is the deepest of the fissures of the olive. The third or caudal principal sulcus

arises from the border of the hilum and may be divided into three equal parts for description (figure 7, *c*). The first portion is deep and broadens out somewhat as it courses laterally. This portion runs directly transversely, to meet with a fairly deep cephalo-caudal secondary sulcus descending from the third lobe. The main fissure then turns somewhat caudally as a deep and very narrow sulcus (the second portion), which ends as a short but deep cephalo-caudal secondary sulcus fuses with it, and the two continue into the third portion, running cephalo-caudally with considerable lateral deflection. It continues around to the lateral surface to form the inferior limit of the third or caudal lateral lobe.

These, then, form the four principal sulci of the dorsal surface of the olive. Unlike the sulci described by Miss Sabin, all of these are continued upon the lateral surface, either directly, as in the case of the cephalic and caudal sulci, or indirectly through the agency of the deep cephalo-caudal fissure as in the case of the middle transverse fissure. Whether or not this deep cephalo-caudal fissure should be considered a principal sulcus is questionable. As seen in the view of this surface (figure 7) the middle transverse sulcus (*b*) continues into it without interruption and it may be considered as merely the lateral continuation of this principal fissure. But the cephalic part of the sulcus, extending caudally from above the first main transverse fissure, argues strongly for its consideration as a principal furrow.

Five distinct lobes may be made out on the dorsal surface as shown in figure 7. These may be considered as the four lobes described by Miss Sabin, with the fifth lobe formed by the dorsal surface of the middle lateral lobe. This fifth lobe lies lateral to the main cephalo-caudal fissure, bounded above by the first transverse fissure and medially and caudally by the fissure to which it lies lateral. The other lobes lie in the regions marked off by the transverse sulci.

The cephalic dorsal lobe is by far the largest of the four, occupying about one-third of the whole olivary nucleus and lying cephalic to the first main fissure (figure 7, *a*). It is subdivided into a superior and inferior portion by a rather shallow sulcus of the secondary order, which travels parallel to the first main furrow. This transverse sulcus takes origin from near the border of the hilum at a point midway between the origin of the first main sulcus and the cephalic end of the hilum. It soon becomes somewhat deeper and sends cephalad a short, broad furrow which contributes to the formation of the gyri in the superior half of the lobe. Continuing lateralwards and becoming quite superficial, it sends caudally, in the middle part of its course, a rather deep but short sulcus, which soon divides into two portions—a caudal projection, becoming superficial over the gyrus above the first main fissures, and a mesial (more marked) furrow which extends mesially toward the hilum and parallels the first main furrow. About these sulci lie the gyri of the medial portion of the inferior half of the cephalic lobe. The secondary transverse fissure, after giving off this caudal sulcus,

continues laterally as a somewhat convoluted furrow, giving off short, superficial sulci; and after deviating somewhat in a caudal direction, it ends by becoming superficial over the lateral portion of the inferior half of the cephalic lobe. Just above the caudal branch of the transverse secondary fissure considered, but separated from it by a gyrus of the superior portion of the cephalic lobe, is a shallow and short furrow, projecting cephalad and laterally to end upon the most cephalic portion of the lobe. Just mesial to the upper end of this short sulcus is a long and somewhat deeper furrow which runs mesially in a straight line for some distance and then abruptly turns caudally and again medially to end superficially at the upper end of the hilum (figures 6 and 7). These constitute the fissures of the cephalic dorsal lobe of the olive; the gyri are quite small in the upper half of the lobe, while in the lower half two large gyri occur, in addition to several small cephalo-caudal gyri. The most lateral gyrus of the inferior half overlies the middle lateral lobe (figures 2, 5, and 7).

Caudal to the first main fissure (*a*) and cephalic to the second transverse fissure (*b*) lies the second dorsal lobe of the inferior olive (figure 7). It is small, being limited on the mesial surface by the hilum, and on its lateral aspect by the deep cephalo-caudal furrow. It consists of but one main convolution, divided into rather narrow and short gyri which wind between a caudal secondary fissure from the first main transverse sulcus and two cephalic furrows from the second main fissure. In the main the long axis of this lobe is exactly transverse, but laterally the lobe is continued caudally in a narrowing spur lying between the cephalo-caudal and the second transverse fissures. This spur dips increasingly deeply into the furrow beneath the general plane of the dorsal surface until at its termination it lies in the depths of the furrows.

Limited by the hilum on the mesial side, by the second (*b*) and third (*c*) transverse sulci cephalad and caudad respectively, and the inferior portion of the cephalo-caudal fissure laterally, occurs the third dorsal lobe (figure 7). In a similar sense this lobe also consists of one main convolution, as in the new-born babe's medulla. But this convolution is marked by many gyri which wind back and forth in a cephalo-caudal direction. The general axis of this lobe lies transverse in the mesial one-third, but laterally to this there occurs a caudal deflection of the whole convolution. The mesial one-third of the lobe is marked off laterally by a caudal fissure, which arises from the depths of the second transverse sulcus (*b*) and rapidly becomes superficial, to vanish over the rather broad gyrus which projects caudally as a peculiar spur into the third transverse fissure (*c*). Mesial to this caudal fissure, there arise from the second transverse sulcus two rather superficial, caudally directed furrows, which aid in producing the gyri of the superior part of the lobe. Lateral to the caudal fissure from the second transverse sulcus is a small and superficial furrow, directed caudally, just mesial to the point of fusion of the cephalo-caudal and transverse sulci. From this

cephalo-caudal sulcus there arises a single caudally directed fissure, short and superficial, separating off a gyrus of the lobe which lies upon the mesial wall of the deep furrow. The portion of this lobe which lies between the cephalo-caudal and third transverse sulci runs caudally and somewhat laterally. This consists of one main convolution, broken into two parallel gyri by a middle superficial sulcus which follows the general direction of the convolution but has a gradual curve, the convexity being mesial. Laterally, the lobe projects around to form the third or caudal lateral lobe (figure 2).

Caudal to the obliquely coursing third transverse sulcus (*c*) lies the caudal lobe of the dorsal surface (figure 7). It is very small and does not extend to the lateral surface. It consists of two main gyri, divided in their mesial portion by a short transverse secondary sulcus, which arises at the caudal end of the hilum. The more cephalic of the two gyri lies more dorsal than the caudal gyrus in its mesial part, but laterally the two gyri approach and fuse with one another to form a flat and wide lateral convolution. The caudal part of the gyrus is continued down as a small spur to form the inferior pole of the olive.

Bounded superiorly by the lateral part of the first dorsal transverse fissure (*a*), and mesially by the cephalo-caudal furrow, the lateral dorsal lobe occurs (figure 7). Its main axis is approximately cephalo-caudal. At the upper mesial part of the lobe there is but one convolution, but as this goes laterally and caudally, it is severed into the two main gyri of the lobe by a fairly deep oblique sulcus which parallels the main cephalo-caudal sulcus for some distance and then curves laterally and caudally to separate the first and second convolutions of the middle lateral lobe. The gyrus lying above this sulcus widens somewhat as it curves upon the lateral surface and shows a shallow but broad groove upon it, becoming the superior convolution of the lateral middle lobe (figure 2). The gyrus lying mesial to and inferior to the sulcus just described, continues inferiorly and slightly laterally as a rather narrow convolution, then rapidly widens out and curves over into the two lower gyri of the lateral middle lobe. The most inferior part of this descending convolution is separated from the main mass by a shallow curving sulcus, which ends as the lateral and dorsal surfaces meet. Above this sulcus the beginning of a rather deep lateral fissure is seen, the furrow which divides the convolution into the two lower gyri of the middle lateral lobe. The most inferior portion of the gyrus is composed of the caudal spur or lowest gyrus of the lateral middle lobe.

The lateral view of the olive (figure 2) suggests, more than any other, the idea of a rotation of the superior pole of the olive. The slope of the main axis of the olive, when viewed from the side, is dorsal in the cephalic region, the mesial part of the cephalic lobe of the dorsal surface projecting far more dorsally than the other two-thirds of the nucleus. The lateral portion of this lobe is somewhat dorsal to the rest of the nuclear mass on lateral view, a fact in accord with the obtuse angle made by the transverse axis of the

olive with the raphe in the cephalic part. Three lobes may be distinguished on the lateral surface, the lateral continuations of the cephalic, lateral, and third dorsal lobes. The main fissures separating these lobes can be made out in their depths only when the olive is viewed from the inferior side as the cephalic lobe overlies dorsally and laterally the first transverse sulcus (*a*), while the lateral dorsal lobe similarly obscures the lateral projection of the dorsal cephalo-caudal fissure.

All the fissures seen on the lateral view have a marked obliquity caudally and ventrally (from above downwards and forwards) in the upper two-thirds of this olivary mass (figure 2). In the lower one-third the sulci run transversely and then curve ventrally and cephalad. No secondary sulci at right angles to the main furrows are made out on this surface, the secondary sulci all being long and shallow, paralleling the direction of the main grooves. The first main lateral fissure, a continuation of the first main dorsal furrow (*a*), is concealed by the overlying gyrus of the lateral cephalic lobe for a portion of its course. About the middle of the lateral surface the furrow becomes superficial and may be traced ventrally and caudally to its ending (figure 5, *a*). Just before its termination at the junction of the lateral and ventral surfaces the sulcus bends abruptly cephalad and ventrally. Superior to this main furrow is a rather long parallel groove which really follows the line of the secondary transverse sulcus of the dorsal cephalic lobe, although interrupted by a small gyrus. Superior to this sulcus are several parallel grooves, which divide this lateral cephalic lobe into many obliquely coursing gyri. Taken as a whole, the lateral cephalic lobe comprising one-half of this surface may be considered as made up of three main convolutions, all of which follow the course of a ventral and caudal projection.

The middle lateral lobe (figure 2) is likewise composed of three chief convolutions, separated by well-marked sulci. The first groove, encountered as one goes caudally from the lateral obliquity of the first transverse dorsal sulcus (*a*), is a parallel and deep sulcus which arises from the lateral end of the transverse furrow and runs caudally, laterally, and ventrally to terminate in the first lateral sulcus as it bends cephalad. The small gyrus, thus delimited by these two oblique grooves, is concealed in its superior half by the overhanging caudal gyrus of the lateral cephalic lobe. The inferior part of this gyrus is readily seen from the lateral surface. Caudal to this gyrus is the first main convolution of the middle lateral lobe—a projecting, flat, broad gyrus which curves obliquely caudalwards, lateralwards, and then ventralwards and cephalad. Shallow, broad, and somewhat indistinct grooves mark its surface. It is bounded below by a fissure which is concealed on this view, the oblique sulcus of the lateral dorsal lobe. Caudally are placed the other two convolutions of this lobe, separated by a shallow crescentic furrow. The middle convolution projects laterally more than do the other gyri, while the lower lobe is distinguished by a caudal projection

or small gyrus, poorly separated by a shallow, ill-defined groove. The inferior convolution shows a marked crescentic outline, the concavity of the crescent being directed cephalad. Inferiorly, this middle lateral lobe is bounded by the lateral termination of the dorsal cephalo-caudal sulcus; the sulcus ends in the mid-line of the lateral surface, but its direction is continued by a short curving groove, which leads cephalad and ventrally.

Inferiorly, there occurs the caudal lobe of the lateral surface (figure 2). This is bounded in its cephalic part by the sulcus just mentioned as forming the inferior limit of the middle lobe. Caudally the lobe is bounded by the lateral superficial ending of the third transverse gyrus and by the pole of the nucleus, which the lobe forms on this surface. The lobe itself is composed of a narrow gyrus on its dorsal side, a continuation of the dorsal third lobe. Just caudal to the spur on the third convolution of the middle lobe, the caudal lobe widens into a broad convolution, which curves ventrally and cephalad into the ventral surface (figures 1 and 5). A single, shallow cephalo-caudal fissure occurs on the ventral one-third of this lateral caudal lobe. The whole caudal lobe comprises one-sixth to one-seventh of the lateral surface.

On direct ventral view (figure 5), the ventral leaf of the inferior olive comprises but the lateral half of the field, while the ventral surface of the dorsal leaf shows in the mesial portion. As described by Miss Sabin in the new-born, the course of the ventral fissures is radial, the central point being slightly inferior to the middle of the ventral border of the hilum. Superior to this point of radiation lies the ventral part of the cephalic dorsal lobe; inferior to it the ventral prolongation of the middle lateral lobe and the dorsal lateral lobe, while far caudalwards, forming the inferior limit of the hilum, occurs the ventral part of the dorsal caudal lobe. The ventral aspect is concerned with a marked ventral bulging of the middle part of its surface, in the inferior portion of the cephalic lobe and in the ventral part of the middle lateral lobe. From this prominence the ventral surface slopes dorsally, both cephalad and caudad, but this slope is soon reduced to fairly flat planes, which curve over into the cephalic and caudal surfaces. The lateral outline, on ventral inspection, exhibits a marked lateral prominence of the inferior portion of the cephalic lobe, overhanging, if such a term be possible, the lateral middle lobe (figures 1 and 5). Caudal to this, the lateral middle lobe develops a lateral prominence in its lower portions, overhanging in turn the lateral caudal lobe, which differentiates itself sharply at a 90° angle from its cephalic neighbor; on the inferior extremity occurs the caudal tip of the caudal dorsal lobe (figures 1, 5, and 6).

From the center of radiation, which really forms the caudal ventral portion of the cephalic lobe, the most striking fissure is that which arises from the cephalic border of the center and passes cephalad in a fairly direct cephalo-caudal direction, to end superficially on the cephalic surface of the cephalic lobe (figures 1 and 5). Between this furrow and the ventral border

of the hilum are several short and shallow furrows, all of which pursue this cephalo-caudal direction. The most cephalic of these courses as a deep groove upon the cephalic pole of the olive, to turn medianly in the axis of the cephalic one-third of the nucleus. Lateral to this prominent cephalo-caudal groove, are three short and shallow sulci running in the same direction. Still lateral to these short grooves occurs the rather deep fissure which marks off laterally the most inferior gyrus of the cephalic lobe on the lateral surface. This sulcus ends at some distance from the center of radiation. Caudal to this occur the notch and suggestive oblique furrow formed by the superficial ending of the first transverse dorsal fissure (*a*), separating the cephalic lobe from the ventral portion of the lateral middle lobe. From the middle of the latter lobe there radiates a shallow groove, directed laterally, caudally, and somewhat dorsally. Below this an interrupted shallow grooving (*b*) marks the caudal ending of this middle lobe on the ventral surface. This grooving actually continues around in the line of the second transverse dorsal fissure. More caudally, the third lateral lobe presents its ventral surface, cut into gyri by two small cephalo-caudal sulci and showing a marked ventral prominence below. On the mesial side this lobe is separated from the dorsal caudal lobe by a short cephalo-caudal furrow, occurring but slightly lateral to the border of the hilum. This small caudal lobe appears Y-shaped on this view, the arms of the Y forming the limits of the hilum inferiorly, while the stem forms the extreme caudal pole.

The cephalic surface of the inferior olive is not shown directly in any of the plates, but a very good idea of its morphology may be obtained from the views of the other surfaces. It is rounded, forming the cephalic covering of the olivary cavity. It is rather deeply grooved by the cephalic continuation of the ventral cephalo-caudal furrow mentioned above. Dorsal and lateral to this deeper furrow occur several superficial grooves, which divide the surface into small gyri.

The caudal surface shows little not already described from the other views. The main portion of this surface is occupied by the caudal lobe which forms the lower limits of the olivary cavity. This lobe, as already mentioned, gives origin to a caudal spur, showing in figures 5 and 6. The superficial ending of the third dorsal transverse fissure (*c*) also shows on the caudal surface of the inferior lateral lobe.

Mesially the hilum occupies the greater portion of the field, showing about it an edge of nuclear material and within it the reverse of the convolutions, especially those on the dorsal surface (figure 6). The general contour of the hilum, with its prominent dorsal border and its ventral border retiring laterally, is very well shown in figure 6. Beginning at the cephalic dorsal angle, the border of the hilum at first goes straight ventrally; it is soon turned abruptly caudally by a caudal projection of the cephalic lobe; then again turns ventrally and somewhat laterally to a small notch in the

cephalic border. After an oblique caudal slope, the border turns straight ventrally for some distance along the edge of the prominent upper cephalic lobe, which is well seen on ventral view (figure 5). This border ends abruptly in a right angle at the level of the secondary transverse gyrus of the dorsal cephalic lobe. From this point the border of the hilum continues caudally in three great curves. The first of these curves, convex dorsally, ends at the level of the first main transverse fissure on the dorsal surface. The border is thence continued in the second curve, convex ventrally, to the level of the second main transverse dorsal fissure. The third curve, arising at this point and showing its convexity ventrally, continues around to the dorsal border, forming in its course the rounded caudal limit of the hilum. The main line of the dorsal border of the hilum is straight, but it is broken by the notches made at the origin of the second and third transverse fissures on the dorsal side (figure 7).

The interior of the olive shows convolutions and sulci, which are in every case merely the reverse of the sulci and gyri described on the opposite surfaces. The caudal end is formed by the caudal dorsal lobe and the third lateral lobes, while the cephalic cap is composed wholly of the cephalic lobe.

The olive is, then, a "hollow shell with a wrinkled wall." The lobes described on the various surfaces merge into one another so that they may be considered as a cephalic lobe, occurring on all the surfaces; a second dorsal lobe, small and only on the dorsal surface; a third dorsal lobe, extending from the dorsal border of the hilum around all the surfaces; a lateral lobe, arising as the dorsal lateral lobe, forming the middle lobe on the lateral surface and continuing over to the center of radiation; and the small caudal lobe. Hence, we may add that the olivary nuclear mass is composed of these five easily distinguished lobes, some of which extend around the whole leaf, while others are small and limited in extent. The three main transverse dorsal fissures exist in the adult as in the new-born (Sabin), but there is in addition a definite cephalo-caudal fissure which continues, in the characteristic caudal obliquity, the lateral projection of the second transverse furrow. These sulci are continued to the point of radiation on the ventral surface, either directly or by a shallow, ill-defined grooving.

The description given above is that of the left inferior olivary nucleus. The right olive was likewise modeled, but with the purpose of showing its relation to the formatio reticularis and to the other nuclear masses (figure 1, cf. two sides). As it can not be removed from its position, an accurate comparison with the left can not be made. However, it may be said that although some slight differences may be made out, even as it lies in the model, the same main fissures and furrows exist as in the left. There is the same characteristic ventral radiation of furrows, the same distribution of lobes on the lateral and ventral surfaces, with consequent agreement of all essential morphological elements.

NUMBER OF CELLS IN INFERIOR OLIVE.

In order to obtain an approximate idea of the number of cells in the inferior olivary nucleus, calculations based on different methods were made. All of the methods used had to do with the volume of the nuclear material comprising the olive. This was determined, as already mentioned, by the displacement of water by the model. This volume was determined as 460 cubic centimeters for the magnification of 15 diameters. From this, the actual volume of the olive was found to be 0.14 cubic centimeter (460 cubic centimeters divided by the cube of 15). To determine the number of cells per cubic centimeter of nuclear material in the olive, counts were made of the cells occurring in the olivary masses, as follows:

(1) The total number of cells occurring in the olive in one section were determined by actual counting of all nuclei by means of traveling back and forth with a mechanical stage. Then the area of the olivary convolutions was obtained by means of a perimeter and the volume computed by multiplying the perimeter value by the thickness of the section (40μ). The volume containing these cells was controlled by cutting out in wax the magnified drawing of the olive in that section and determining the volume of the wax. By this method the olive was found to contain 950,000 cells.

(2) The area of a high-power field of the microscope was determined by measurement and the volume of the field computed by multiplying the area by the thickness of the section. All the cells were then counted in a number of fields and the average value used in the computation for the total number of cells. By this method, which may be considered as fairly accurate as soon as one learns to count accurately the cells in a field, the nuclei in the olive were found to be 1,050,000. This value is an average of many counts, the highest being 1,068,000 and the lowest 1,038,000 by this method.

(3) The third method used for determining the cells in the olive was that of counting the cells occurring in a definite square projected into the field of the microscope from squared centimeter paper by an Abbe camera lucida. The exact size of this field could be determined readily by measuring a ruled slide (0.1 millimeter) in terms of the centimeters on the squared paper. The volume of this square was then determined by multiplying the area by the thickness of the section. Further computations were then made to secure the number of cells in the total volume of the olive. By this method the total number of nuclei in the olive was found to be slightly less than 1,100,000, and a value but slightly above that determined by counting the total cells in the measured microscopic field. The nucleoli were also counted by this method and found to be 530,000 in one inferior olivary nucleus.

Considering the second and third methods to be far more accurate than the more laborious first method, it may be said that the total number of nuclei (both of ganglion and neuroglia cells) in one inferior olive is between 1,000,000 and 1,100,000; the number of nucleoli is about 500,000. These counts were made in conjunction with Dr. Essick, to whom credit for the methods used is gladly given.

NUCLEUS OLIVARIS ACCESSORIUS MEDIALIS.

Placed between the stratum interolivare and the inferior olivary nucleus, but separated from the latter by the fibers of the nervus hypoglossus, is the nucleus olivaris accessorius medialis. This medial accessory olive is a flattened irregular cell-mass, arising caudally considerably nearer to the decussatio pyramidum than the inferior olive, but extending cephalad to a point somewhat caudal to the cephalic pole of the inferior olivary body (figure 4). In cephalo-caudal extent, it practically equals that of the olive, beginning and ending caudally to the corresponding points on the main nucleus. As a broad, thin sheet of cells it covers almost completely the hilum of the olive on the mesial side, although the cell-masses are lacking somewhat along the dorsal border. The whole nuclear mass of this medial accessory olive is shown in figure 4.

The nucleus olivaris accessorius medialis, on the left side of this adult medulla, consists of a continuous flat and broad column of cells, presenting two constrictions in the mass and also showing separated nuclear masses at different portions of the whole extent. Beginning abruptly in the formatio reticularis, the caudal portion of the main mass of the medial olive quickly widens into the broadest portion of the whole mass. The general direction of this portion is obliquely lateral, making an angle of about 135° with the raphe. With the broadest portion existing at the level of the inferior olivary pole, this sheet of cells, convex medially, continues upward to the level of the third dorsal transverse fissure, where it exhibits a marked constriction. Just caudal to this constriction its dorsal border is continued posteriorly into a well-marked projection lying entirely behind the general line of this border. Undoubtedly this constriction corresponds to the division between the caudal and middle cell-masses found by Sabin in the new-born, but in the babe the degree of constriction is apparently far more marked. Above this constriction the main cell-mass extends as a continuous, fairly broad sheet to the level of the first dorsal transverse fissure. The ventral border of this portion is slightly curved with the convexity dorsally. The dorsal border, from the point of constriction, gradually and irregularly projects more dorsally, until at the level of the second dorsal transverse fissure it juts suddenly dorsally, to form the neck of an irregular cell-mass (figure 4). This new cell-mass is almost square from mesial view, showing a deep notch on its cephalic surface and separated from the main mass of the mesial olive by a still deeper notch. Its pedicle is rather broad, but is perforated by a distinct band of fibers. The main nuclear mass, after an abrupt ending of the principal broad column of cells at the level of the first transverse fissure, is continued cephalad by a narrow mass of cells which stretches dorsally and cephalad to widen above into an irregular cephalic broadening. This broadened mass exhibits a dorsal projection in its superior half and a sharper, narrower ventral spur at its cephalic pole.

Such, then, is the main sheet of cells comprising the mesial accessory olive. In the main, it shows the same primary divisions as found by Miss

Sabin in the new-born medulla, but it differs from her reconstruction in the fact that the cephalic cell-mass is connected with the middle mass, and in the fact that the constriction between the caudal and middle lobes is not as marked in the adult as in the reconstruction of the new-born.

Dorsal to the caudo-dorsal portion of the inferior olivary nucleus, and lateral and somewhat dorsal to the lower part of the main cell-mass of the mesial accessory olive, is a short and small, regular column of cells, belonging to the mesial accessory olive. This lies very closely related to the inferior portion of the caudal lobe. It probably corresponds to the cell-collection lying dorsal to the caudal column of cells as described by Miss Sabin. At the dorsal border of the hilum, on a level with the secondary transverse dorsal fissure and with the cephalic portion of the medial accessory olive, is another cell-mass, rather shorter but broader and thicker than the one described as lying dorsal to the caudal cell-mass. This mass undoubtedly corresponds to the small collection of cells found dorsal to the superior column in the new-born. Ventrally and somewhat laterally, the cephalic portion of the main cell-mass in the adult is continued into two irregularly shaped collections of cells, the lateral and larger of which lies behind the other on mesial view. Just cephalic to the superior ventral angle of the middle cell-mass of the mesial accessory olive there lies laterally a rather larger and quite regular cell-mass, whose cells resemble those of the mesial olive and should undoubtedly be considered as belonging to the same complex.

No cell-masses, corresponding to the two collections lying dorsal to the middle column of cells in the new-born, were modeled in the adult (figure 4). The two dorsal spurs, the inferior arising from the superior dorsal angle of the caudal division and the superior from the middle of the dorsal border of the middle division, may perhaps be the analogies of these two dorsal cell-masses. Such a view has considerable support in the great range of variations seen in the divisions of nuclear material effected by the nerve fibers.

Lying along the middle three-fifths of the ventral border of the main cell-sheet of the mesial accessory olive, is an irregular cell-column (figure 4). This column also lies upon the pyramids. Histologically, there is more correspondence to the structure of the arcuate nuclei than to the mesial olive, but its relation to the mesial accessory complex may be assumed by virtue of its position (figure 11). The caudal portion of this arcuate-olivary column is attached to the cephalic portion of the caudal division of the main cell-sheet, but no other connection with the mesial olive is made out. This column shows a gradual dorsal prolongation just inferior to its middle portion and a small but prominent ventro-lateral spur above its middle. It ends just caudal to the cephalic ending of the middle division of the main cell-mass, projecting somewhat mesially in its more superior part. This cell-mass is easily made out in figure 1.

The right medial accessory olive, as modeled and fixed in position to show constantly its relationships, shows, as far as can be made out, the same

three divisions of the main nuclear sheet. The constriction, however, between the caudal and middle lobes, is further accentuated by the presence of a large fenestration in the cell-sheet, made by the coursing fiber bundles. The cephalic division is not large nor well marked off, but it follows, in the main, the same general direction and relationship as does the corresponding mass on the opposite side. Dorsal to the middle part of the middle division is a somewhat larger dorsal projection than on the opposite side, but it has very similar characters (figure 1). The caudal lobe at its cephalic dorsal angle also has a spur corresponding closely to the spur on the opposite side. Small nuclear masses occur just above this spur. These are not found on the left side.

NUCLEUS OLIVARIS ACCESSORIUS DORSALIS.

The nucleus olivaris accessorius dorsalis sinister is a thin sheet of cells, about one-third the length of the olive and slightly less than one-half its transverse diameter. As a more or less rectangular plate, it overlies dorsally the second and third dorsal lobes, and is represented in outline in figures 5, 6, and 7. It is shown in part in figure 4. Beginning caudally just cephalad to the third transverse fissure (*c*) of the dorsal surface it rapidly widens to its line of greatest transverse diameter over the second dorsal fissure (*b*) and thence continues cephalad in a slightly narrowing body to an abrupt ending over the first dorsal fissure. Its mesial border at the inferior end lies slightly lateral to the dorsal border of the hilum, but soon approaches and corresponds to that border. Hence, the dorsal accessory olive lies over the dorsal middle and mesial third of the main nuclear mass. Dorsally, it is covered by the formatio reticularis. The surface of the dorsal accessory olive is smooth, but it shows a slight convexity ventrally, the point of greatest convexity being over the deep second dorsal transverse sulcus (*b*). The right nucleus, as far as can be made out, corresponds fairly exactly to the left. The nucleus has approximately the same extent as that in the new-born, as reconstructed by Miss Sabin.

THE PONTINE COMPLEX.

In this reconstruction, the nuclear material of the caudal portion of the pons, of the nuclei arciformes, and of the corpus ponto-bulbare was modeled. The description of these structures will deal with these as portions of a single morphological unit, as they are undoubtedly portions of the same primary cell-mass. Essick (1912) has shown that the pontine nuclei are formed from cells migrating in the embryo from the Rautenlippe of His in the lateral wall of the fourth ventricle, along the course of the corpus ponto-bulbare, which he first described in 1907. This, then, necessarily includes the corpus ponto-bulbare in the pontine nuclei. Somewhat similarly the arcuate nuclei are formed from cells which migrate superficially around the surface of the medulla from the Rautenlippe. These arcuate nuclei are of

the same histological structure as are the pontine nuclei, and at the lower end of the pons the arcuate nuclear material insensibly passes into the pontine masses. It is believed, from consideration of these factors, that any description of these nuclei should deal with the three nuclear masses as integral parts of one main nuclear mass. This plan will be followed in the description, the arcuate nuclei and the corpus ponto-bulbare being considered first, and then the pontine nuclei as the cephalic portion of these integral parts.

Inspection of a number of brain-stems cut in serial sections will lead to the conclusion that marked differences exist in the amount of nuclear material comprised in the arcuate nucleus and in the corpus ponto-bulbare. Some of the series will show great amounts of this gray matter scattered along the course of the fibræ arciformes externæ ventrales with large redundant arcuate nuclei, while in other brain-stems the amount of these peripheral cell-masses is meager and very small. With such marked diversity in the extent of the nuclear material along the ventral surface of the medulla, each reconstruction must be considered wholly from the standpoint of the presentation of the nuclear material in that particular brain-stem. Similar differences exist in the amount of the cellular material comprising the corpus ponto-bulbare. The adult brain-stem, which has here been reconstructed, is very poor in the nuclear matter comprising both of these cell-masses and the resulting model of these two cell-columns must be taken as indicative of the extent and course of the masses rather than as the morphological form for every brain-stem. Similar differences, of course, exist in all nuclear masses, but these differences are not in the main sufficient to change appreciably the morphology.

NUCLEI ARCIFORMES.

The nuclei arciformes in this reconstruction exhibit considerable differences on the two sides of the model, as can be seen from figure 1. Neither of them is a continuous cell-mass, but both are interrupted about the middle of their extent. Both begin at approximately the same level caudally, just caudal to the inferior termination of the nucleus olivaris accessorius medialis. Both finally terminate by merging with the pontine nuclei at the caudal extremity of the pons, their extent being about coincident with that of the inferior olive.

The arcuate nucleus on the left side begins caudally as a flat, rather thin sheet of cells, which is placed in the midst of the ventral external arcuate fibers, ventral to the pyramids. With the smallest diameter dorso-ventral, the column can be traced cephalad (figure 2) as a continuous cell-mass to slightly superior to the point of radiation on the ventral leaf of the olive. In this extent of the lower continuous mass, the column shows a lateral convexity, so that even the upper end of this first portion of the nucleus is placed lateral to the inferior end. Two marked lateral notches are seen on the mesial border in its convexity. Just caudal to the inferior of these notches is a well-defined lateral projection (figure 1). A much smaller

lateral projection shows a similar relation to the superior of the notches. The caudal end of this portion is rounded and shows a widened transverse portion, cephalic to which the nucleus preserves almost intact its transverse diameter. The cephalic end of this first portion of the left arcuate nucleus inclines somewhat ventrally, as shown in figures 2 and 4. At the superior end of this first portion, two small masses of nuclear material occur, separated from each other and from the superior cell-column of fiber bundles. These, with their long axes transverse, are shown in figures 1, 2, and 4. They lie cephalic, mesial, and slightly ventral to the cephalic pole of the first portion. The superior of these lies more cephalic, mesial, and ventral than the inferior. Cephalic to these small nuclear masses, the arcuate nucleus on the left again becomes a continuous mass which runs to the pontine nuclei. As shown in figure 1, the whole column shows a marked convexity toward the mid-line and also a curving, so that the superior end is drawn dorsally before it projects ventrally in the pontine enlargement. The mesial margin of this part is irregularly curved toward the mid-line (figure 1); the lateral margin shows a marked mesial notch, superior to which it projects irregularly laterally to fuse with the pontine nuclei. The nuclear material in the middle of this part is split into two masses which soon unite (figure 1). Cephalic to the union of these two masses, the ventral surface is smooth and widens gradually; about its middle is a gradual ventral ridge shown in figures 1, 2, and 4.

At the level of the caudal end of the separation of this left arcuate nucleus into two columns, there occur cell-masses belonging to the arcuate system, dorsal to the ventral mass, lying deeply along the side of the anterior longitudinal fissure as it deepens into the foramen cæcum. A small irregular cuboid mass and a more ventral elongated mass appear in figure 4 at this level. Somewhat superior to this, the lateral surface of the longitudinal fissure is lined by a cell-column which joins the ventral arcuate mass in a gentle curve (figure 4). This dorsally projecting cell-column is thickened at its ventral origin, but soon becomes a slender spur. Cephalic to this, the whole arcuate plate curves around to the mesial surface. This is continued into two marked dorsal spurs before it merges with the pontine nuclei which surround the pyramids. The middle of these dorsal spurs is projected toward the mid-line in a ridge-like eminence. The whole arcuate complex, curving around the pyramids and exhibiting the characteristics mentioned, is shown in figure 4. The fusion of this convex plate with the ventral pontine nuclei is well shown. The inner surface (lateral and dorsal) of this curved complex is grooved by cephalo-caudal fissures and marked by a single ridge which lies in the same plane as the cuboid mass and runs in the same cephalo-caudal direction.

The right nucleus arciformis is considerably different from the left, which has just been described. In general, it consists, like the left, of a slender caudal mass of cells which widens laterally and curves about the mesial side of the pyramids cephalad to fuse with the pons. The most caudal

cell-mass of this right arcuate nucleus begins slightly caudally to the left as a rather broad and thin column of cells which decreases in transverse diameter very quickly (figures 1 and 10). Reaching a fairly constant transverse diameter, the cell-column extends cephalad (figures 11 and 12), with a very marked lateral convexity. It terminates abruptly cephalad on a level below the superior ending of the first portion of the left arcuate. Its superior pole terminates much farther laterally than on the left. This allows it to approximate the olive more closely as the pyramids decrease laterally in their dorso-ventral diameter. The middle of this first portion of the right arcuate is marked by a deep lateral notch on its mesial surface.

Cephalic to this first portion, the curve of the right arcuate nucleus is further continued medially by a small isolated mass of arcuate material, irregularly shaped (figure 1). Superior to this irregular mass, on a level with the division of the left arcuate in two columns, lies the caudal end of the cephalic portion of the right nucleus arciformis. This shows on ventral view (figure 1) as two caudally projecting columns, the mesial being more caudal. This mesial spur is really the ventral border of a mesial plate, similar to that on the other side, which extends from this point to the pontine nuclei. It is quite a thick plate, bordering the deepened anterior longitudinal fissure and placed mesially to the pyramid. It shows a number of short dorsal spurs, more numerous and less extensive than those on the left. This mesial plate curves around the pyramids into the ventral plate, at the caudal lateral corner of which is the lateral of the spurs. Above this spur is a fairly deep, well-differentiated furrow, with a cephalo-caudal direction. The middle of this portion shows the same gentle ventral ridge as exhibited on the opposite side. The lateral margin of this portion of the nucleus is irregular and shows but little lateral deflection until it suddenly widens into the ventral portion of the nuclei pontis. The ventral and mesial plates fuse without irregularity into the caudal portion of the pontine nuclei. The inner surface (lateral and dorsal) of this curved plate of cells is marked by longitudinal fissures and furrows, similar, in all main characters, to those which occur on the left. These ridges are continued upward to mark the course of the pyramids through the nuclei pontis (figure 13).

The two arcuate nuclei fuse in the mid-line, the connection taking place just dorsal to the anterior longitudinal fissure (figure 1). Both mesial plates send out a rather heavy nuclear column and these merge in the mid-line. The connection, however, ceases before the pons is reached. In the pons, of course, the mid-line connection of the two nuclei can be assumed.

CORPUS PONTO-BULBARE.

This body—which Essick (*loc. cit.*) showed to extend from the emergent fifth nerve caudally between the seventh and eighth nerves and to terminate in the lateral wall of the fourth ventricle just caudal to the dorsal nucleus of the cochlear nerve—has been modeled in this reconstruction. Only those

parts, however, which contained sufficient nuclear material to justify modeling have been included. As one passes from the spinal cord cephalad in series, the corpus is first met in the lateral wall of the ventricle just dorsal to the caudal half of the medial vestibular nucleus. This most caudal portion of the corpus is shown in the reconstruction as an oval of nuclear tissue on the dorsal surface of the middle of the caudal half of the medial vestibular nucleus (figures 2 and 3). Traced from this point cephalad, the corpus for a short distance loses most of its nerve-cells. As the amount of nuclear material is not sufficient to justify modeling, no connection is shown in the model between this most caudal oval and the more cephalic portions. The tract next becomes sufficiently endowed with nuclear material in the region just caudal to the most inferior portion of the dorsal cochlear nucleus. Here it is represented (figures 1, 2, and 3) by a thin sheet of cells, lying caudal and mesial to the dorsal cochlear nucleus. It is curved by the corpus restiforme upon which it lies. Its cephalic border is prolonged ventrally, mesially to the dorsal cochlear nucleus. An abrupt termination has been given to the corpus at this point by the ending of the sections in the block of tissue used as a unit for embedding. It is met, however, as soon as the correction for loss in the blocks is made, lying mesial to the caudal extremity of the ventral cochlear nucleus in the same dorso-ventral plate. This is shown in figure 3. From this point, the corpus ponto-bulbare is represented by a continuous cell-mass stretching to the nuclei pontis. Beginning here, mesial to the caudal limit of the ventral cochlear nucleus, the corpus forms at first a widening mass of cells with the long axis transverse (figures 1, 3, 12, and 13). Shortly after its origin, it spreads transversely toward the mid-line in an irregular arm of nuclear tissue which stretches mesially and somewhat dorsally toward the substantia gelatinosa and the nucleus of the seventh nerve. Two small cell-masses occur ventral to this arm (figure 1). The main cell-column of the corpus passes cephalad, ventrally, and slightly laterally, following the line of the ventral cochlear nucleus. It broadens somewhat at the cephalic limit of this nucleus and gives origin to two mesially and dorsally projecting arms, one of which fuses with the cell-column from the spinal nucleus of the vestibular nerve and the other with the column from the superior nucleus, as these two columns meet the entering vestibular nerve. These two projecting arms from the corpus ponto-bulbare are marked by great irregularities—by spurs projecting in every direction, by sudden increases and decreases in diameters, and by small isolated cell-masses occurring along the course of the nerves. The cephalic end of the mesial of these two arms comes into contact with the substantia gelatinosa. The main cell-mass of the corpus, decreased in size after the projection of these two arms, continues cephalad beyond the cephalic pole of the ventral cochlear nucleus. This is shown in figures 1, 2, and 3. A thinner mesial column of cells accompanies the main mass (figure 1, especially). The main mass and the smaller mesial column extend cephalad with a slight ventral

deflection (figure 2), and at the caudal end of the nuclei pontis the main cell-mass is deflected mesially, still maintaining its ventral deviation. The mesial column of cells joins very quickly the main cell-column as it is deflected mesially and the two combine into an irregularly shaped cell-mass which soon fuses with the pontine nuclei (figures 1 and 3). This mesially inclined portion of the corpus is split into two masses in part of its course; it possesses numerous spurs and other irregularities throughout its course.

Not directly connected with the main cell-mass, but separated by a small distance at the point where the main cell-mass of the corpus ponto-bulbare deflects mesially, is a long, heavy cell-column which stretches from this point to the superior termination of the model. This irregular cell-column, placed in the midst of the brachium pontis, extends ventrally and cephalad in a fairly straight course (figures 1, 2, and 3). It possesses at its caudal end a considerable knob-like dilatation, but as it passes cephalad it becomes flattened transversely. Just cephalic to the caudal end the cell-column divides into a smaller mesial portion, which slowly approaches the nuclei pontis, and the main lateral column which continues the straight cephalo-ventral course. Between these two cell-columns and the main mass of the pontine nuclei are many bizarre nuclear masses. Some make direct connection between the two masses of nuclear material; others are merely isolated cell-clusters; others are short columns. All combined render the picture one of great complexity, as shown in figure 1 especially and in figure 3 to a lesser extent.

On the right side of the model, the corpus ponto-bulbare has been modeled from the mesial side of the ventral cochlear nucleus to the pons. It shows the same general characteristics as are shown in the left side of the model.

The significance of all these irregular collections of cells occurring in the brachium pontis is probably the same as that of the corpus ponto-bulbare, of which they should be considered a part. The corpus probably joins with the nuclei pontis in many different ways in the different adult brain-stems, but in general this complicated and bizarre plan of the numerous cell-masses in the brachium pontis must be granted. This is surely substantiated by the consideration of the conception that the corpus ponto-bulbare is the pathway along which migrate the nerve-cells which are to form the nuclei pontis; and in such a migration, the possibility of the existence of scattered cell-masses in the brachium pontis of the adult is very great.

NUCLEI PONTIS.

The pontine nuclei, in this reconstruction, have been modeled in their caudal portion, extending cephalad to the limit of the model. For the most part, no account has been taken of the transversely coursing fiber-bundles because of the fact that these bundles are discrete and usually extend only through three or four sections of 40 micra each. This renders reconstruction of the individual nuclear masses in the nuclei pontis practically impossible,

and worthless from a morphological standpoint. However, on the lateral surfaces of the pons the fiber-bundles do make fairly definite pathways in the gray matter, permitting these to be modeled with some benefit. The gray matter surrounding the longitudinal fibers of the pyramids has been modeled, and all of the longitudinal fibers in the neighborhood of the main mass of pyramidal fibers have been cut away. This gives rise to the resulting nuclear shell about the pyramids, not shown in any of the drawings of the model, but seen in figure 14 on cross-section.

The nuclei pontis in the caudal part may be considered as a huge mass of cells surrounding the pyramids. The portion dorsal to the pyramids takes its caudal origin just inferior to the superior pole of the nucleus olivaris inferior (figure 2), while the ventral portion is extended caudally into the nuclei arciformes (figure 1). The lateral portion is continuous caudally with the corpus ponto-bulbare (figure 1). The pyramids take a fairly direct cephalo-caudal direction through the portion of the pontine nuclei modeled, although at the superior end of the model they are divided into many separate bundles by invading spurs of nuclear material (figure 14). With the dorsal portion, arising caudally near the superior pole of the oliva, its cell-mass quickly enlarges in all directions and joins with the ventral portion, at the cephalic end of the arcuate nuclei, to surround the pyramids. This is shown in figure 2, the pyramids of course not appearing in the drawing. As soon as the pyramids are completely surrounded by gray matter, the pontine nuclei enlarge cephalad in all directions (figures 1, 2, and 4). The dorsal portion extends dorsally as one goes cephalad; the lateral portion extends laterally; and the ventral extends ventrally. Such, then, is the general ground plan of the pontine nulcei in the caudal portion modeled.

When viewed laterally (figure 2) the relations of the corpus ponto-bulbare and the arcuate nuclei to the pontine nuclei are evident. The caudal margin of the pontine nuclei extends in a dorso-ventral direction from the mesial and ventral plates of the arcuate nuclei, surrounding the pyramids and fusing with the small dorsal part of the pontine mass. From this point of fusion the lateral border, caudally, takes a cephalic deflection and a general dorsal course, so that it comes into relation with the nucleus nervi trigemini and its substantia gelatinosa (figures 2 and 14). This lateral wall is, in its caudal part, merely a thin sheet of cells projecting dorsally far beyond the limits of the main nuclear mass. From lateral view, the ventral margin shows the continuation of the ventral curve exhibited by the most cephalic portion of the arcuate nuclei. This convexity continues upward for some distance with the assumption of almost an exact cephalo-caudal direction; it is ended in an angle to be succeeded by a second ventral convexity. This change in direction probably corresponds to the irregular surface-markings of the ventral bulging of the pons. The whole lateral surface shows a cephalo-lateral deviation from the longitudinal plane and also a gradual convexity from its dorsal border around the pyramids to the mid-line. This

surface is marked by excessive irregularities, as shown in figures 2 and 14. The striking features of these irregularities lie in the direction of the spurs and in the nuclear connections between the corpus ponto-bulbare and the pontine nuclei, which have already been described. The surface is studded by the spaces filled by the ponto-cerebellar fibers as they leave the pons to course through the brachium pontis to the cerebellum. Between these fiber-bundles numerous nuclear spurs project in a dorso-lateral direction. The character and abundance of these spurs is shown in figure 2; they are most numerous and typical in the middle of the lateral surface, where they are extensive, large, and separated by deep fiber fenestrations.

As one moves from the lateral to the ventral surface, the surface irregularities are seen to change gradually until they assume a fairly typical form on the ventral surface. Here the surface (figure 1) shows short and shallow furrows, deeper sulci, and many ridges more or less extensive. These run in all directions in the upper part, although in the most caudal portion their long axes are in the main transverse. The ventral surface exhibits the ventro-cephalic deflection above noted and two convexities merging in the mid-line in an irregularly delimited furrow. The lateral walls of this mid-line depression, as shown in figures 1 and 4, are marked by bizarre spurs and notches. The base of the furrow is marked by irregular corrugations and is wider than its ventral opening. It is filled with transversely coursing fiber-bundles which give rise to marked perforations of the lateral nuclear walls.

On mesial view (figure 4) the mass of nuclei pontis is shown cut along the mid-line. The more cephalic origin of the caudal part of the pontine nuclei, in the mid-line, is well shown. The mesial plate of the arcuate nucleus has become fused with the ventral portion of the pontine nuclei, some distance caudal to the point where the pontine nuclei cross the mid-line. The dorso-cephalic slope of the main dorsal pontine cell-mass is shown extending from the dorsal margin of the mesial plate of the arcuate nucleus. This surface is met, in the middle of its course in the model, by the dorsal margin of the nuclear material which crosses the mid-line. This dorsal margin of the mid-line gray matter is shown in figure 4, as an irregularly notched and fissured border, with three chief notches and two caudal projections marring its outline.

The dorsal surface of the nuclei pontis is not shown in any of the drawings, but its outline appears in figure 4. Beginning caudally at a rather sharp pole just caudal to the superior termination of the oliva, this dorsal surface, as one progresses cephalad, widens out dorsally and laterally. It quickly joins with the mesial and ventral plates of the arcuate nucleus to surround the pyramids. When viewed from the dorsal side, this surface shows two ventral concavities which end in mesial and lateral dorsal projections. The lateral projection forms the nuclear plate of the lateral pontine wall, while the mesial dorsal projection runs along the mid-line to expand into the nucleus reticularis tegmenti pontis (figures 4 and 14). Between the

two dorsal projections is the main concavity of the surface of each side. This becomes less marked as one goes cephalad. The surface is irregularly fissured and furrowed, showing between these groovings many small dorsal projections.

The relations of the dorsal end of the lateral plate of the pontine complex with the nucleus of the nervus trigeminus are worthy of comment. On a level with the superior pole of the nucleus nervi facialis the lateral plate of the pons projects dorsally and meets the substantia gelatinosa just as that merges into the sensory enlargement (figure 4). This projection of tissue from the nuclei pontis lies mesial to the lateral wall of the complex and the lateral cell-mass overhangs it. The separation of the nuclear material from the pontine nuclei and that composing the trigeminal complex is very difficult. Traced cephalad from the caudal point of union of the trigeminal nucleus and the pontine nuclear material, the connection between the dorsal pontine mass lying mesial and ventral to the trigeminal nucleus is broken for a considerable extent. This is shown in figure 2. The dorsal mass of pontine cells projects in a laterally directed ridge and then suddenly recedes as the connection is again made at the upper extremity of the model. Here the connection between the dorsal pontine mass and the lateral wall of the nuclei pons is quite massive. On mesial view the dorsal pontine mass is seen to extend quite a distance dorsally toward the mesial eminence on the surface of the fifth nucleus.

The *nucleus reticularis tegmenti pontis* (Flechsig) is the dorsal projection of the mesial portion of the dorsal surface of the nuclei pontis. It really represents a portion of the nuclei pontis lying along the mid-line of the tegmentum and projecting dorsally almost beneath the floor of the fourth ventricle (figure 14). Its mesial outline is shown in the transparency of figure 4 as the irregular continuation of the dorsal surface outline of the pontine nuclei. As modeled, the nucleus shows two distinct portions, a marked laterally projecting mass, irregular in extent and marked by a bizarre surface, situated midway between the dorsal surface of the nuclei pontis and the floor of the fourth ventricle, and a second dorso-lateral projection beneath the nucleus incertus in the floor of the ventricle. These two masses are connected by a broad irregular bridge of nuclear material. The more ventral of these two masses shows a gradual increase in extent as it proceeds cephalad; at its caudal portion it is marked by a deep cephalo-caudal furrow. It continues beyond the cephalic limit of this model. Its surface is marked by many irregularities, especially by deep fissures. The dorsal of the two masses projects dorso-laterally as a bizarre and heavy cell-column, which shows a peculiarly shaped triangular caudal projection (figure 4). The dorsal surface curves laterally and dorsally beneath the nucleus incertus. This spur recedes as it goes cephalad and, after a marked notch, a second dorso-lateral spur takes its place beneath the nucleus incertus. This terminates as the superior margin of the model is reached (figure 4).

The course of the pyramids through the portion of the nuclei pontis included in this model is almost a direct longitudinal one. At the caudal end of the pontine nuclei, the pyramids form a solid column of fibers surrounded by the cell-mass of the pons. The cross-section in this area (figure 13) shows them to be almost round. The investing nuclear wall is smooth, marked only by the longitudinal ridge mentioned as occurring on the inner surface of the plates of the arcuate nuclei. As the pyramids are traced cephalad, small spurs project from the including nuclear tissue separating the fibers. Cephalic to these small spurs, occur cell-bridges which divide off a portion of the fibers from the chief bundle of the pyramids. These cell-bridges increase in number and extent, breaking the pyramids up into smaller collections of fibers. Such, then, is the course of the pyramids through the pons, as shown in this reconstruction. This is not given in any of the drawings of the model, but the breaking up of the main bundle of the pyramids appears in the cross-section (figure 14).

NUCLEUS OLIVARIS SUPERIOR.

The nucleus olivaris superior begins just caudally to the middle of the nucleus nervi facialis and, sloping dorsally and slightly laterally, terminates cephalad in the region of the sensory enlargement of the nervus trigeminus (figure 4). It measures in its longest diameter 9.0 millimeters. It lies along the ventro-mesial surface of the nucleus of the seventh nerve in its extent and then gradually approaches the ventral portion of the mesial surface of the nucleus nervi trigemini. It is mesial to the lateral wall of the pontine nuclei. On its mesial side and ventral side lies the formatio reticularis, in which it occurs; superior to the nucleus of the seventh nerve, it has formatio reticularis also on its dorsal and mesial aspects (figure 13).

The caudal termination of this nucleus olivaris superior is a pointed pole lying in close approximation with the ventro-mesial surface of the nucleus of the seventh nerve. It is shown in figure 4, the mesial view of the model. This inferior portion of the nucleus is poorly defined and is separated with difficulty from the nucleus of the seventh nerve, even though the latter possesses a characteristic histology. The nucleus enlarges into a triangular nuclear mass, out of which three dorso-ventral cell-columns appear clearly defined. These are united at their ventral aspect and they spread out from this ventral point as spokes from a hub. Dorsally the ends of these ridges are joined together at a level slightly superior to the point of ventral radiation. The two cell-columns which form the nucleus arise from the ventral and dorsal points of union, respectively, and run cephalad, dorsally, and somewhat laterally (figure 13).

The mesial column arises from the ventral point of radiation in the caudal cell-collection, as a small continuous cell-mass. This quickly and abruptly enlarges into a thin sheet of cells which run cephalad in the characteristic direction. This sheet of cells lies in the general dorso-ventral plane,

but its ventral border is placed more laterally from the mid-line than its dorsal margin. The mesial surface is smooth and slightly curved, with a mesial convexity extending cephalad for half of the extent of the nucleus, where it forms a marked notch. The surface then extends mesially in a small shoulder. Just posterior to this notch is a deep caudal incision, dorsal to which appears a similar, somewhat thicker sheet of cells (figure 4), which merges with the mesial cell-column, the two ascending as a widened, thickened cell-sheet in the characteristic direction of the columns in the nucleus. Just caudal to the cephalic termination, the ventral border turns abruptly dorsally and then cephalad, decreasing the width of the cell-sheet by almost one-half. This is quickly followed by the abrupt cephalic ending of the nucleus, the cell-sheet disappearing very quickly. The ventral border of this mesial cell-column shows a slight ventral projection somewhat cephalad to its caudal origin. Slightly above this, the dorsal border exhibits a dorsal projection (figure 4). The mesial surface is smooth, but in the caudal half is marked by a slight eminence and in the ventral portion of the cephalic half a similar eminence occurs. Cephalic to this superior elevation, the mesial surface shows a slight concavity. The lateral surface of the mesial cell-column is quite irregular and rough. At a point corresponding to the notch in the mesial surface, a marked irregular lateral projection occurs on this surface. At the superior pole there is considerable thickening of the nucleus in the transverse diameter.

The lateral of the two cell-columns is really double throughout the middle portion of its extent, although it arises singly from the mesial surface of the dorsal union of the three primary radiate columns. Arising from this union, the column extends as a triangular cell-column, placed dorsally and somewhat mesially to the dorsal border of the mesial column. It approximates in part the ventro-mesial border of the nucleus nervi facialis (figure 4). It continues cephalad somewhat irregularly, in the characteristic dorsal deflection, with slight lateral deviation. At the level of the superior pole of the seventh nucleus a marked and smooth dorso-mesial spur is given off. At this point the cell-column bends laterally and dorsally across the superior pole of the olive and then pursues a cephalo-lateral course to fuse quickly with its second portion. This second portion of the lateral column arises just caudally to the superior pole of the seventh nucleus as an elongated oval, with the long axis in the dorso-ventral plane. It ascends cephalad and fuses with the lateral cell-mass after its abrupt lateral deflection. Here the combined cell-column, oval in shape, lies lateral to the mesial collection. It passes cephalad in the characteristic direction of these cell-columns, flattening out as a dorso-ventral sheet of cells. As such, it abruptly terminates just caudal to the lateral projection on the lateral surface of the mesial cell-column. Hence the lateral column possesses only half the longitudinal extent of the mesial cell-mass.

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EXPLANATION OF PLATES.

KEY TO LEGENDS IN FIGURES.

ab, Undescribed nucleus (cf. text, p. 27) (orange).
ac, Nucleus alæ cinereæ (purple).
am, Nucleus ambiguus (uncolored).
ar, Nucleus arciformis (yellow).
cg, Substantia grisea centralis (uncolored).
co, Nucleus nervi cochleæ (purple).
cu, Nucleus fasciculi cuneati (red).
fr, Formatio reticularis (uncolored).
ft, Nucleus funiculi teretis (green).
gr, Nucleus fasciculi gracilis (yellow).
in, Nucleus intercalatus (blue).
ic, Nucleus incertus (purple).
la, Nucleus lateralis (green).
mc, Anterior motor column (red).
od, Nucleus olivaris accessorius dorsalis (orange).
ol, Nucleus olivaris inferior (uncolored).
om, Nucleus olivaris accessorius medialis (orange).
os, Nucleus olivaris superior (violet).
pb, Corpus ponto-bulbare (yellow).
po, Nuclei pontis (yellow).
ro, Nucleus of Roller (green).
ts, Nucleus tractus solitarii (uncolored).
ve, Nucleus nervi vestibuli (green).
vm, Nucleus motorius nervi trigemini (uncolored).
vs, Nucleus sensorius nervi trigemini (blue).
vi, Nucleus nervi abducentis (red).
vii, Nucleus nervi facialis (uncolored).
xii, Nucleus nervi hypoglossi (red).

Fig. 1. Drawing of the ventral aspect of the whole model (× 7.5). The heavy pontine mass is prolonged caudally in the form of interrupted arcuate nuclei. The latter bow away from the mid-line on both sides and lie in front of the two olivæ. At their termination the anterior columns of the spinal cord extend to the base of the model. The outlines mark the configuration of the brain-stem and end cephalad to the lateral recess. Along the margins are given the levels of the sections, represented in figures 8 to 14.

Fig. 2. Drawing of the left lateral aspect of the model (× 7.5). The prominent pontine nuclei overhang the olive and an arrow passes through the roughened tunnel in the gray material formed by the pyramidal tract in its crossing. The ventral limit of the brain-stem is outlined in its entire extent. Dorsally the margin is discontinued at the dorsal cochlear nucleus, where it runs toward the cerebellum as the anterior wall of the lateral recess.

Fig. 3. Drawing of the dorsal aspect of the model (× 7.5). To the right of the mid-line, the nuclei of the upper cervical cord are represented, but where the central canal expands into the fourth ventricle the smooth surface of the floor has been retained. On the left side, all the nuclear masses have been modeled separately. The ink line marks out the configuration of the brain-stem as far as the outline is not a knife cut made in preparing the specimen.

Fig. 4. Drawing of the mesial aspect of the left half of the model (× 7.5). The pontine mass, the nucleus reticularis tegmenti pontis, and the caudally projecting arcuate nuclei are represented as transparent. The central canal of the spinal cord is shown in dotted lines which are continued into the fourth ventricle as far as the nucleus intercalatus. The surface form is represented in outline on the ventral side, while dorsally this line is continued in the region of the anterior wall of the lateral recess, as in figure 2.

Figs. 5, 6, 7. Drawings of the ventral, mesial, and dorsal aspects, respectively, of the nucleus olivaris inferior (× 7.5). The first, second, and third primary fissures are designated in these figures by the constant initials of *a*, *b*, and *c*, on the ventral and dorsal surfaces. The form and position of the nucleus olivaris accessorius dorsalis is portrayed by a simple outline.

Figs. 8, 9, 10, 11, 12, 13, 14. Drawings of cross-section (× 2.4) representing respectively sections 5, 200, 400, 500, 600, 700, and 900, which have been selected from the series used in this reconstruction. The accompanying outline drawings show the limits of the nuclear masses, with the same color representations as in the other figures. The position of these sections in the model is given by the various section-levels in the first four figures.

PLATE I

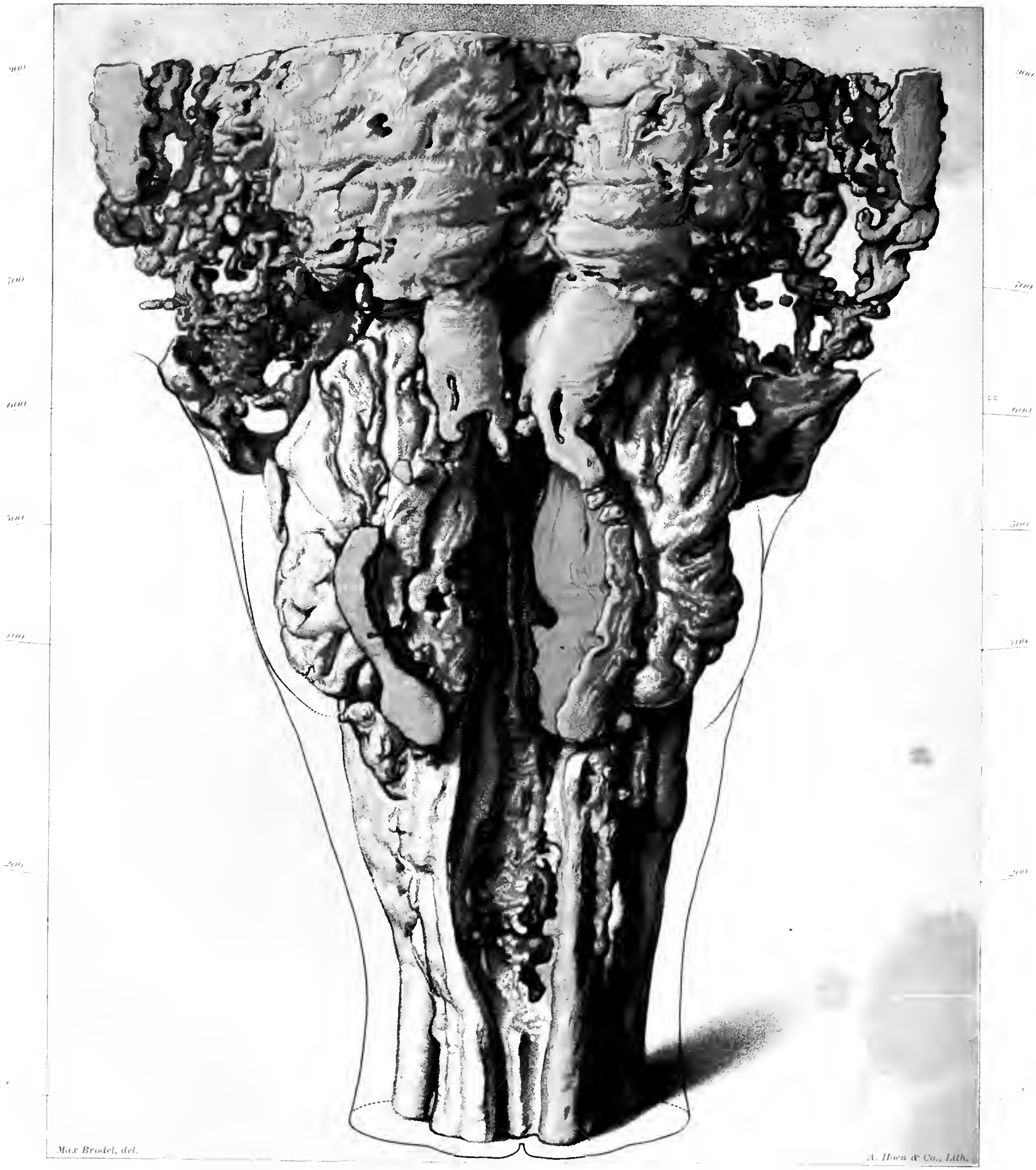
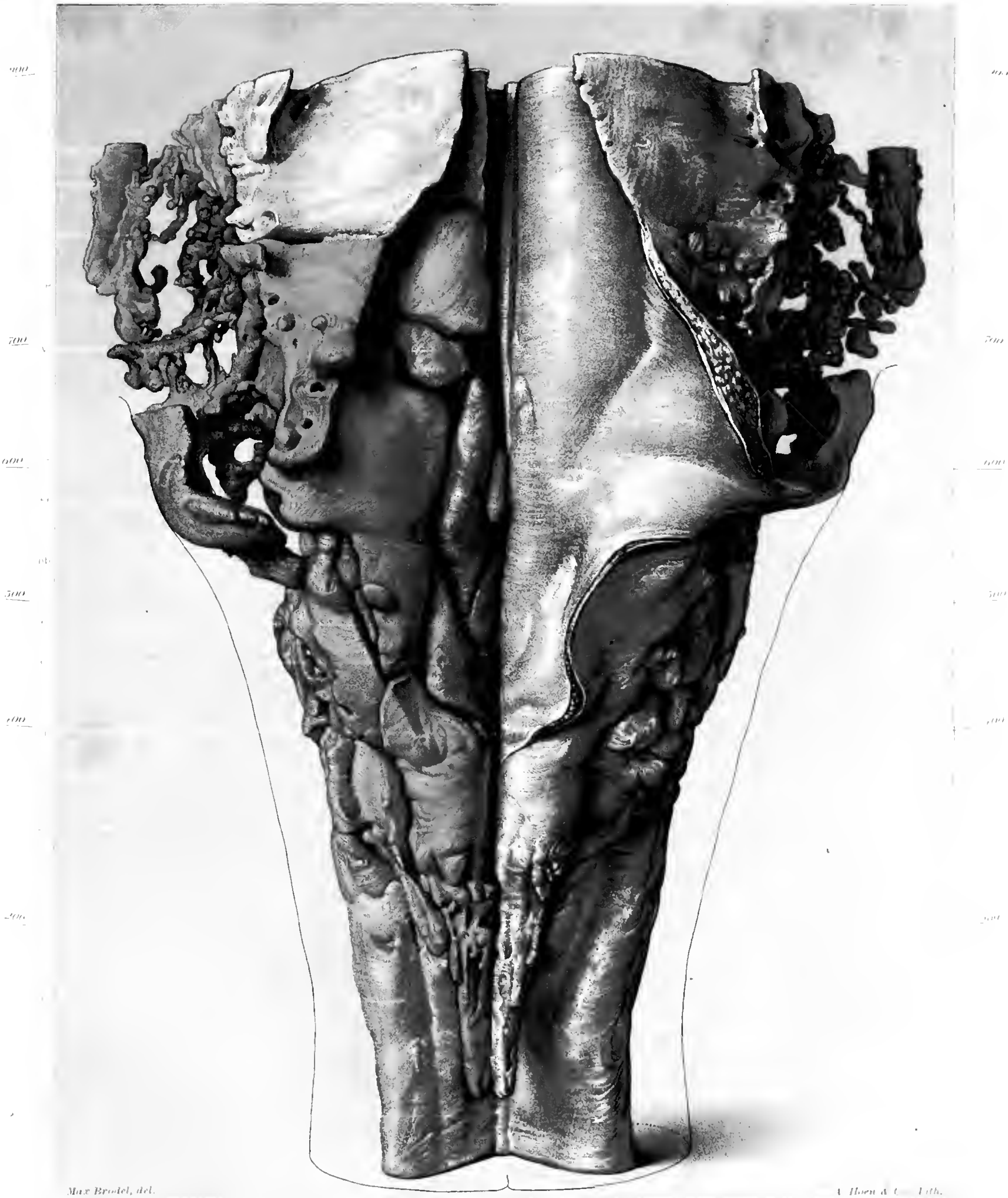


Fig. 1

Max Brodel, del.

A. Hoen & Co., Lith.

Fig. 2

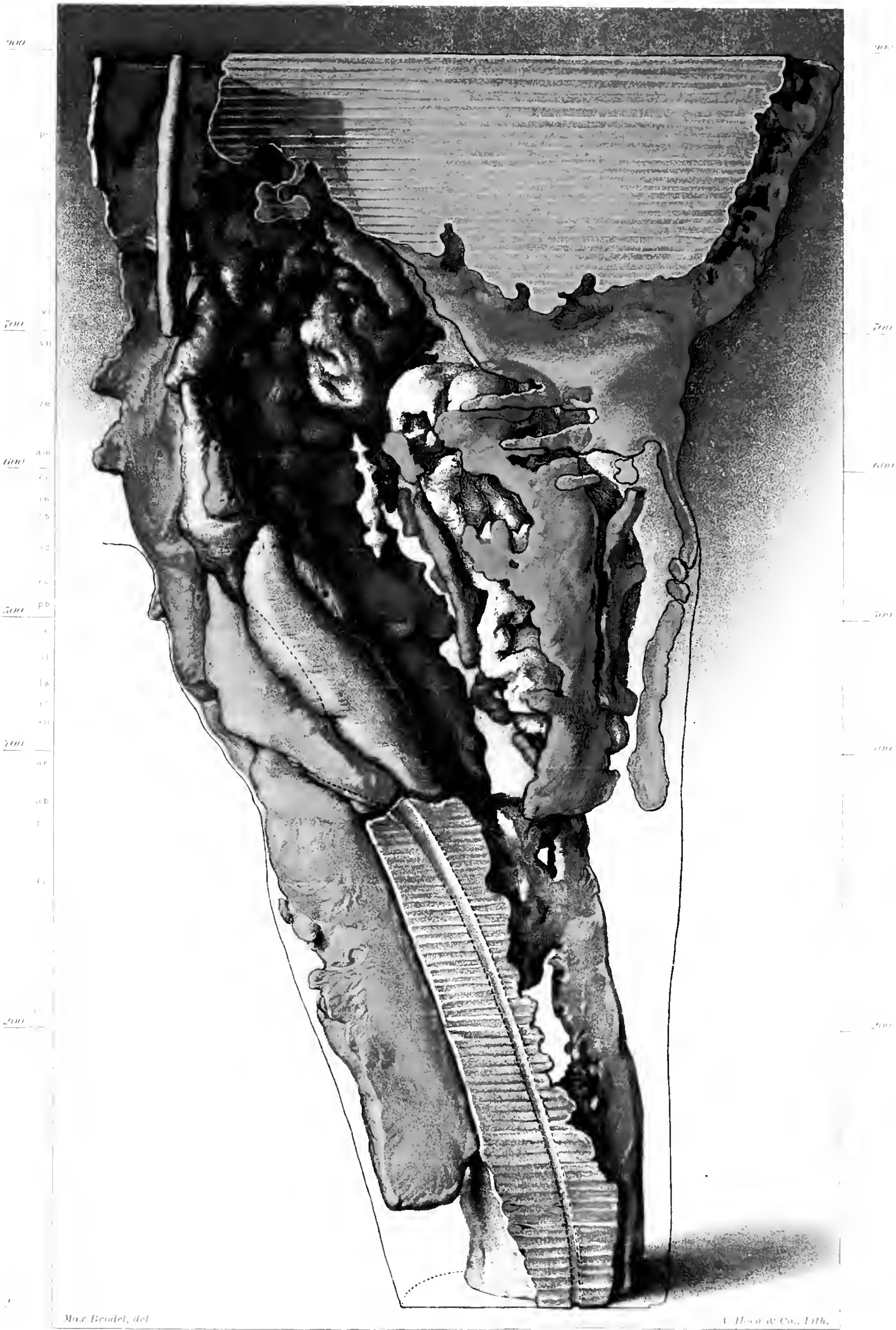


Max Brödel, del.

A. Hoen & Co. Lith.

Fig. 3

PLATE V



Max Brödel, del

A. Hoen & Co. Lith.

Fig. 4

PLATE V

Fig. 5

Fig. 6

Fig. 7

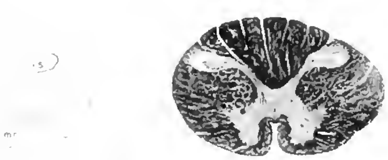


Fig. 8

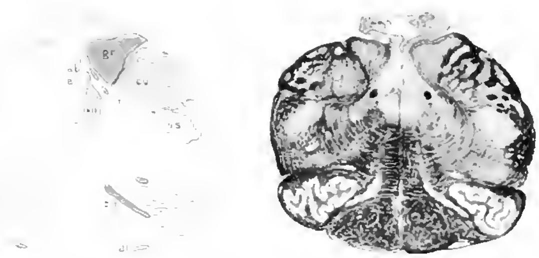


Fig. 10

Fig. 9

Fig. 11

PLATE VI

Fig. 12

Fig. 13

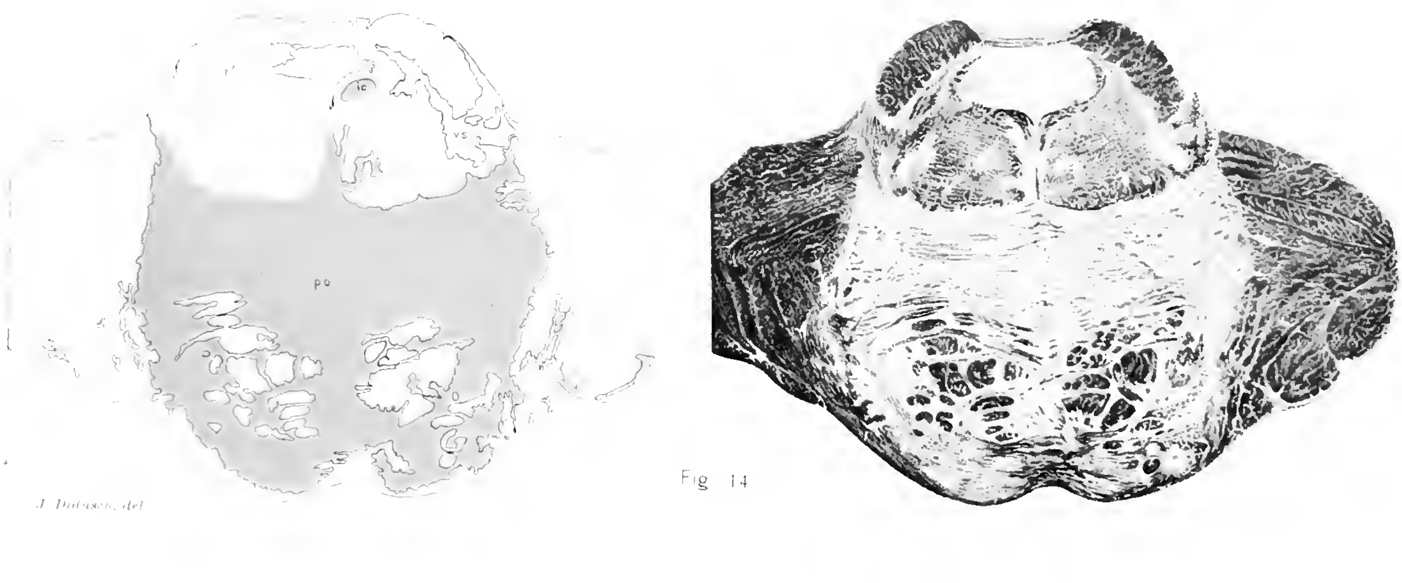


Fig. 14

J. Dobson, del.

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